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AGING OF ELASTOMERS IN CANDU PRESSURE BOUNDARY SERVICE

by

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AGING OF ELASTOMERS IN CANDU PRESSURE BOUNDARY SERVICE

ABSTRACT

This report describes the properties and aging of elastomers, and examines the performance of major elastomeric components in CANDU pressure boundary service. The components examined are:

(1) vacuum building roof seals
(2) pressure relief duct seals
(3) airlock door seals
(4) fuelling machine hoses
(5) cable penetrations

For each of these components, the design requirements, technical specifications and component testing procedures are compared with applicable standards. Information on actual and recommended monitoring and maintenance methods is presented. Operational and environmental stressors are identified. Component failure modes, causes and frequencies are described, as well as the remedial action taken. Many different elastomers are used in CANDU plants, for many different applications. Standards and manufacturers' recommendations are not consistent and may vary from one component to another. Accordingly, the monitoring, maintenance and replacement practices tend to vary from one application to another, and may also be different at different stations. Recommendations are given in this report for improved monitoring and maintenance, in an attempt to provide more consistency in approach.

A summary of some experiences with elastomers from non-Canadian sources is contained in the last section.

VIEILLISSEMENT DES ÉLASTOMÈRES DANS L'ENVELOPPE SOUS PRESSION CANDU

RÉSUMÉ

Le présent rapport décrit les propriétés et le vieillissement des élastomères, et examine le rendement des principaux composants en élastomère dans l'enveloppe sous pression CANDU. Les composants examinés sont :

1) les joints d'étanchéité du toit du bâtiment à vide
2) les joints d'étanchéité de la conduite du bâtiment à vide
3) les joints d'étanchéité de la porte du sas
4) les tuyauteries de la machine de chargement du combustible
5) les pénétrations des câbles

Pour chacun de ces composants, les exigences de conception, les spécifications techniques et les méthodes d'essai des composants sont comparées avec des normes applicables. On présente l'information

sur les méthodes actuelles et recommandées de contrôle et d'entretien. Les éléments de contrainte opérationnels et environnementaux sont identifiés. Les modes, les causes et les fréquences de défaillance des composants sont décrits, ainsi que les mesures correctives à prendre. De nombreux types d'élastomères sont utilisés dans les centrales de type CANDU, pour une foule d'applications distinctes. Les normes et les recommandations des fabricants ne sont pas uniformes et elles peuvent varier d'un composant à l'autre. Par conséquent, les pratiques de contrôle, d'entretien et de remplacement ont tendance à varier d'une application à l'autre, et elles peuvent différer aussi suivant la centrale. Des recommandations sont faites dans le présent rapport pour améliorer le contrôle et l'entretien, afin de fournir une méthode plus uniforme.

La dernière section renferme un résumé de certaines expériences avec les élastomères menées à l'extérieur du Canada.

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A. Standards of American Society of Testing and Materials applicable to elastomers
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A. INTRODUCTION

1. Background

As nuclear power generating stations become older, the issue of aging of various critical components becomes more important. Considerable attention is focussed on the effect of aging on the performance of metals used in the structure of nuclear reactors, but little effort has been made so far, towards understanding, monitoring and managing time-related degradation of polymeric materials such as elastomers.

Manufacturing of elastomeric components often takes the following route:

(1) raw material, such as rubber gum, is supplied by one of the major chemical companies

(2) the raw material is compounded into a molding formulation by either the molder or by an intermediate compounder

(3) the product is molded by the molder and supplied to the user

Using the same raw material and various additives, a range of compounds can be produced with widely different properties. Each manufacturer has developed his own range of products. Compositions are usually considered proprietary, and are not disclosed to the user.

There are three main reasons why detailed studies have so far not been performed on elastomers:

(1) From a safety point of view the materials are generally considered to be less critical than metals. Degradation and replacement of elastomers are accepted at the design stage as expected occurrences.

(2) These materials are not standardized to the same extent as metals. Their compositions are usually quite complex and are not disclosed by suppliers, making rigorous studies of aging difficult.

(3) There are almost no non-destructive testing techniques suitable for the monitoring of the components during use.

This report, sponsored by the Atomic Energy Control Board, is a step towards documenting and understanding the aging and service wear of elastomers, as used in CANDU pressure boundary service.

To provide an indication of the age of the nuclear stations discussed in this report, the following list gives the first commerical operation dates for CANDU reactors:

Station Name	Commercial Operation	MWe Gross	Operator	Comments
NPD	1962	25	Ontario Hydro	
Douglas Point	1968	218		Shutdown 1985
Pickering A Unit 1-4	1971-1973	542		
Pickering B Unit 5-8	1983-1986	540		
Bruce A Unit 1-4	1977-1979	826		
Bruce B Unit 5-8	1985-1987	865		
Darlington Unit 1-4	1989-1991	936		
Gentilly 1	1972	266	Hydro Quebec	Shutdown 1978
Gentilly 2	1983	685	Hydro Quebec	
Pt. Lepreau	1983	680	NBEPC	
Wolsung	1983	678	Korea	
Embalse	1983	648	Argentina	
Cernavoda	1989	680	Romania	First of 5 reactors

Most of the information in this report relates to Pickering A and Bruce A, since these are among the oldest operating CANDUs.

2. Objective

Various pressure boundary components in CANDUs are elastomers, which have failed occasionally due to aging and wear. The objective of this study is to review standards/requirements, operating experience, to identify failure modes and causes, to review existing monitoring methods and maintenance practices, and to recommend practical and cost effective means of maintaining and monitoring elastomeric components.

3. Project Scope

For the following pressure boundary components in CANDU reactors:

(1) Vacuum Building Roof Seals

(2) Pressure Relief Duct Seals

(3) Airlock Door Seals

(4) Fuelling Machine Hoses

(5) Cable Penetrations

aging, service wear, inspection, surveillance, monitoring and maintenance practices were investigated.

The following information was obtained and reviewed:

(a) design information, specifications, and application guidelines;

(b) regulatory requirements and industrial standards in Canada;

(c) information on operation, inspection, surveillance, monitoring, and maintenance policies, guidelines, and procedures, including manufacturer's recommendations;

(d) information on actual practices (as compared to the prescribed or recommended practices) concerning operation, inspection, surveillance, monitoring, and maintenance;

(e) information required to determine operational stressors (e.g resulting from testing, plant cycling, and trips) and environmental stressors that could cause time-dependent degradation;

(f) records of operation, inspection, surveillance, monitoring and maintenance experiences, including records of failures and degradation (e.g. Quarterly Technical Reports, Significant Event Reports, Component Failure Data Base for CANDU Nuclear Plants, In-Service Inspection Reports). [Ref. 1]

For comparison, pertinent non-CANDU experience, i.e. LWR reactors, was reviewed to the extent practicable.

B. PROPERTIES AND AGING OF ELASTOMERS

1. Properties of Elastomers

Elastomers consist of a number of components. The polymer content is often 50% or less. The balance is made up of components such as inorganic fillers, plasticizers, antioxidants, antiozonants, accelerators, curing agents, and other minor components. All contribute to and affect the properties of the final product. Generalizing properties of generic types of elastomers is not possible since there may be significant differences in the concentrations of the various components within one type. The following information was compiled from the references 2, 3, 4 and 5.

Classification of Elastomers

A standardized terminology system classifying elastomers based on the polymeric backbone is recommended by ASTM D1418 "Rubber and Rubber Lattices - Nomenclature." These classes are:

"M" Class - saturated main chain, examples:

EPDM - terpolymer of ethylene, propylene and a diene
EPM - copolymer of ethylene and propylene
CSM - chlorosulfonated polyethylene

"O" Class - oxygen in the main chain, examples:

CO - polyepichlorohydrin

"R" Class - unsaturation in a main chain, examples:

CIIR - copolymer of chloroisobutene and isoprene
CR - polychloroprene
IR - polyisoprene
SBR - copolymer of styrene and butadiene

"Q" Class - silicone in the main chain. Prefixes indicate the following substitution:

M - methyl
V - vinyl
P - phenyl
F - fluorine

Examples, VMQ - vinly methyl silicone

U" Class - elastomers with carbon, nitrogen and oxygen in the main chain, typically polyurethanes.

Examples, AU - polyester based polyurethanes
EU - polyether based polyurethanes

Some of the most common classes of elastomers are described below. The elastomers used in CANDU nuclear reactor systems are separately identified.

(a) Natural Rubber (NR)

Main Properties: Good resiliency, tensile and tear strength, impact and abrasion resistance, low hysteresis, good resistance to water, alcohol and dilute acids, oxidation, weathering, high temperature, flammability, oils, hydrocarbons, concentrated acids and bases.

Service temperature: minimum $-60^{o}C$
maximum $120^{o}C$

Applications- pneumatic tires, tubes, transmission belts, gaskets, shock absorbing elements, sponges.

(b) Polyisoprene (IR)

Main Properties: similar to those of natural rubber, somewhat better resistance to oxidation and inorganic acids somewhat lower tensile and tear strength.

Service temperature: minimum $-50^{o}C$
maximum $80^{o}C$

Applications- same as natural rubber

(c) Polybutadiene (BR)

Main Properties: mechanical properties somewhat lower than those of natural rubber, better resistance to abrasion and flex cracking.

Limited resistance to ozone, weathering, fuels, oils and lubricants.

Service temperature: minimum $-65^{o}C$
maximum $+125^{o}C$

Applications- pneumatic tires, soles, gaskets, seals, belting, used in blends with other rubbers.

(d) Isobutylene Isoprene (IIR)

Main Properties: Mechanical properties lower than those of natural rubber, polybutadiene, and styrene-butadiene, poor resistance to fuels and oils. Low gas permeability, high electric resistance and dielectric strength, high resistance to ozone, oxidation, weathering and water. Good resistance to steam, alcohols, esters, acids and heat aging.

Service temperature: minimum -50°C
maximum 150°C

Applications - truck and auto tire, inner tubes, steam hose, diaphragms, electrical insulation, and vibration absorption.

(e) Styrene - Butadiene (SBR)

Main Properties: excellent abrasion and impact resistance, good flex crack resistance, good resistance to water and alcohol, poor ozone resistance and poor resistance to hydrocarbons.

Service temperature: minimum -60°C
maximum 120°C

Applications- same as natural rubber and polybutadiene.

(f) Chlorinated Elastomers

There are five major chlorinated elastomers:

-chlorinated isobutylene isoprene
-polychloroprene (CR) (known as Neoprene)
-chlorinated polyethylene (CM)
-chlorosulfonated polyethylene (CSM) (known as Hypalon
-epichlorohydrins (CO and ECO)

Main Properties: chlorine improves resistance to fuels and oils as well as fire resistance. Good resistance to ozone, oxidation, weathering, water, fuels, alcohols and heat aging.

Service temperature: minimum -60°C (ECO)
-50°C (others)
maximum 107°C (CR)
163°C (others)

Applications- wire and cable, belts, hose, adhesives, gaskets, petroleum and chemical tank linings, and hoses.

Neoprene and Hypalon are used in CANDU reactor systems. Neoprene is used for the Pickering Vacuum Building Roof Seal, in several seals in the Pressure Relief Valves at all multi unit stations and in the pressure relief duct expansion joints at Pickering A. Neoprene was also used in the early airlocks seals at Douglas Point and Pickering. Hypalon is being introduced as a fuelling machine hose jacket material at Bruce A and B, as a replacement for Neoprene. The hose jacket material is still Neoprene for Pickering and the CANDU 600s.

(g) Acrylic Rubbers (AR)

Main Properties: excellent resistance to sulfur bearing oils and fluids, good resistance to ozone, oxidation, weathering and aliphatic hydrocarbons. Poor resistance to aromatic and halogenated hydrocarbons, alcohols, acids, only moderate tensile strength and abrasion resistance, poor resistance to flex cracking, tear and impact.

Service temperature: minimum -40°C
maximum 210°C

Applications- automotive ignition wire jackets, spark plug boots, power steering hose, motor mounts, and transmission seals.

(h) Acrylonitrile Butadiene (NBR)

Commonly called nitrile or Buna N.

Main Properties: Good resistance to oils and fuels. Mechanical properties better than those of acrylic rubber. Low permeability, high resistance to water, good resistance to non-oxidizing acids, and moderate resistance to weathering.

Service temperature: minimum -50°C
maximum +150°C

Applications- gasoline, chemical and oil hose, gaskets, seals, O-rings, and conveyor belts.

Fuelling machine hose internals were originally Buna N at Bruce A and B, and are still Buna N at Pickering and the CANDU 600s.

(i) Ethylene Propylene Diene (EPDM)

Main Properties: good electrical resistivity and dielectric strength, good resistance to ozone, oxidation, weathering, water, steam and heat aging, good resistance to radiation dilute acids, bases, alcohols, ketones and esters, good resistance to abrasion, impact and flex cracking.

Service temperature: minimum -55°C
maximum +150°C

Applications- electrical insulation, hoses, conveyor belts, pipe and tank linings, vibration mounts.

Ethylene propylene diene is currently used for the Bruce A and B vacuum building roof seals, for the rolling diaphragms in the Pressure Relief Valves at Pickering, the Bruce Stations, and Darlington, and for the seals in the bulkhead panel.

(j) Fluorocarbons (FPM)

Main Properties: good resistance to fuels, oils, hydraulic fluids, heat, ozone, oxidation, weathering, and good tensile strength.

Service temperature: minimum -50°C
maximum 280°C

Applications- high temperature seals and other high temperature components, lined valves, and roll covering shaft seals.

(k) Polysulfide (PTR)

Main Properties: excellent resistance to fuels, oils, alcohols, ketones and esters, good resistance to ozone, oxidation and weathering, low permeability to gases, poor mechanical performance.

Service temperature: minimum -40°C
maximum +120°C

Applications- seals, gaskets, diaphragms, hose in contact with solvents, valve seats, and flexible mounting.

(l) Silicones

MQ - methyl silicone
VMQ - vinyl methyl silicone
PMQ - phenyl methyl silicone
PVMQ - phenyl vinyl methyl silicone
FVMQ - flurine vinyl methyl silicone

Main Properties: excellent resistance to oxidation, weathering, good resistance to arcing ozone and corona, poor mechanical properties. Silicones containing phenyl groups (PMQ, PVMQ), show improved resistance to radiation.

Service temperature: minimum -110 to -55°C
maximum 200 to 300°C

Applications- high and low temperature electrical insulation seals, gaskets, diaphragms, and O-rings.

The replacement vacuum building roof seals for Pickering, Bruce A and Bruce B are silicone rubber. Airlock door seals are also silicone rubber, as are the pressure relief duct expansion joints for Pickering B.

(m) Polyurethanes

AU - polyester based polyurethanes
EU - polyether based polurethanes

Main Properties: excellent mechanical properties such as tensile strength, tear and abrasion resistance, excellent resistance to ozone and oxidation, poor resistance to halogenated hydrocarbons and acids, good low temperature performance.

Service temperature: minimum -50°C
maximum 120°C

Application- tubing, bladders, seals, gaskets, wheels, casters, O-rings, and rolls.

A urethane compound is used around the piping penetrations through the Pickering B bulkheads.

2. Aging of Elastomers

Aging may be defined as reduction of properties of materials subjected to various external elements (stressors) over a prolonged time period. The stressors causing aging of elastomers include:

- elevated temperature
- radiation
- ozone
- hydrocarbons (oils, fuels)
- mechanical stress
- high pH/low pH chemicals

These stressors usually act in conjunction with one another, resulting in rather complex degradation mechanisms.

2.1 Heat Aging

Pure thermal aging in the absence of oxygen is of little industrial interest since most components are exposed to environmental oxygen. It is the oxygen in conjunction with heat which is the main cause of elastomer aging. It is a free radical reaction involving cleavage of C-H bonds. In order for the thermo-oxidative reaction to take place oxygen has to diffuse into the elastomer. If oxygen is consumed faster than it can be replenished, the rate of degradation will be diffusion limited. Heterogeneous degradation takes place - oxygen is available near the surface only and only a limited or no supply of oxygen is available in the centre.

The rate of oxygen diffusion is a function of mechanical stress applied to the part. Because of that, stress accelerates the oxidative degradation of elastomers. [Ref. 6]

ASTM D2000 "Classification System for Rubber Products in Automotive Applications," provides for the classification of elastomers based on their resistance to heat. Elastomers are classified into the highest temperature at which they

can satisfy the following requirements after 70 hours exposure: hardness change ±15 points, tensile strength change ±30% and ultimate elongation change ±50%. Heat resistance is rated as:

Temp.(°C)	70	100	125	150	175	200
Type	A	B	C	D	E	F

Because of the short exposure time, this test is not representative of the performance of the part in a long term service.

2.2 Degradation by Ozone

The concentration of ozone in the atmosphere is very low but it can cause considerable damage to elastomers. Ozone reacts with double bonds present in rubber compounds. If the elastomer is not stretched, a very thin sticky film of degraded polymer is formed on the surface and no further damage occurs to the part.

If the elastomer is subjected to a stress, ozone causes formation of surface cracks which then propagate, leading ultimately to failure of the part. For elastomers sensitive to ozone, a concentration as low as 0.0005% is adequate to initiate cracking. The rate of degradation is a function of the type of rubber, the specific formulation, mechanical stress, temperature and ozone concentration.

2.3 Low Temperature Performance

Elastomers stiffen when subjected to low temperature. The increase in stiffness may be caused by a number of factors:

- loss of mobility of polymeric chains (the temperature at which this happens is called the glass transition temperature and is usually designated Tg).
- reduction of plasticizer/polymer solubility
- crystallization of polymer

All three phenomena are fully reversible; elastomers return to their original properties when brought back to higher temperatures.

2.4 Damage by Oils and Solvents

Oils and solvents damage the properties of elastomers by:

- diffusing into the elastomer and causing swelling. Hardness, tensile strength and stiffness decrease, elongation at break may increase or decrease.

- leaching out plasticizers and other components of the elastomer. Hardness, stiffness and sometimes tensile strength increase; elongation decreases. ASTM D2000 classifies elastomers based on swelling in oil (ASTM Oil No.3) after 70 hours at the temperature specified for a given type (see page 10). The classes are designated as follows:

Table 1: Classification of Elastomers Based on Swelling in Oil (from ASTM D2000)

Class	A	B	C	D	E	F	G	H	J	K
Volume Swell %	No Require-ment	140	120	100	80	60	40	30	20	10

2.5 Degradation by Mechanical Stress

Degradation by mechanical stress may be divided into two classes, depending on the effect of the stress:

- stress accelerates the rates of various degradation reactions (for example, oxidation or ozone attack)
- stress more directly causes a change of the elastomer.

The most common examples of mechanical stress degradation are:

- fatigue; damage caused by cyclic stress;
- creep; dimensional change due to constant load
- stress relaxation, slow stress decay of the elastomer subjected to constant strain.

2.6 Degradation by Radiation

2.6.1 Effect of Dose

Ionizing radiation penetrates organic materials deeply. Cobalt 60 gamma radiation (1.17 to 1.33 MeV) will pass through a thickness of organic rubber of well over 1 m before it is completely absorbed. [Ref. 7] The result of irradiation is a change of mechanical properties - the elastomer may lose its elasticity, become brittle and susceptible to cracking; other elastomers may become soft, cheesy and tacky. [Ref. 8] Two competing reactions take place:

- cross-linking
- chain scission

Cross-linking increases hardness, stiffness and often tensile strength but reduces elongation, while chain scission has generally the opposite effect on properties. If irradiation takes place in the presence of air, oxygen plays an important role in the aging process - a process similar to thermal oxidation takes place. Tensile strength, elongation and hardness as functions of radiation doses were tested by CERN for a number of elastomers. Samples were irradiated in the 7 MW ASTRA pool reactor at Seibersdorf (Austria). [Ref. 9] A typical set of curves is shown in Figure 1.

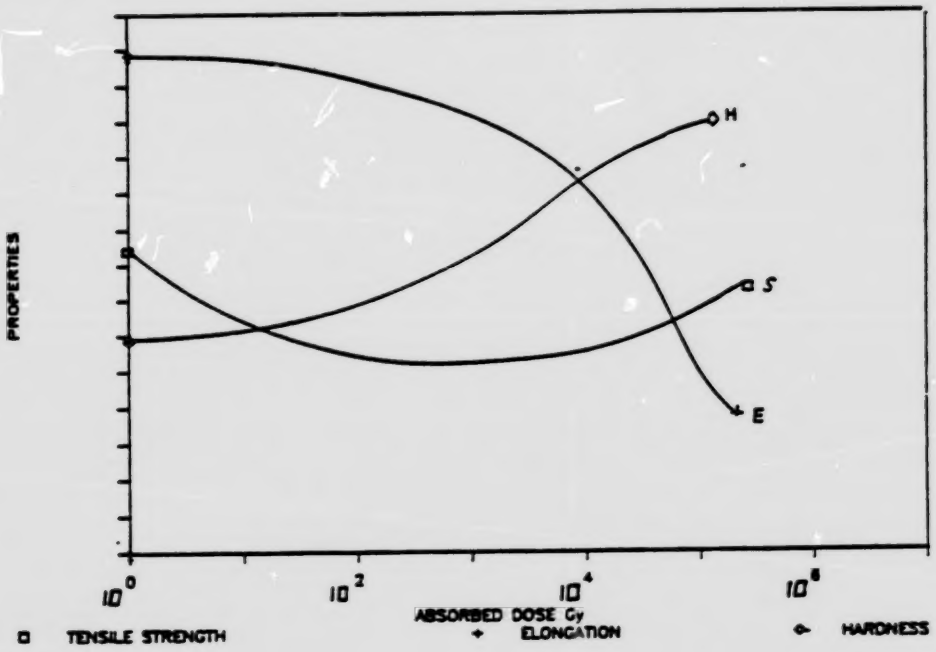


Figure 1: Tensile strength, elongation at break and hardness as functions of radiation dose [Based on Ref. 9]

The general resistance of various elastomers to gamma radiation is shown in Figure 2. [Ref. 10]

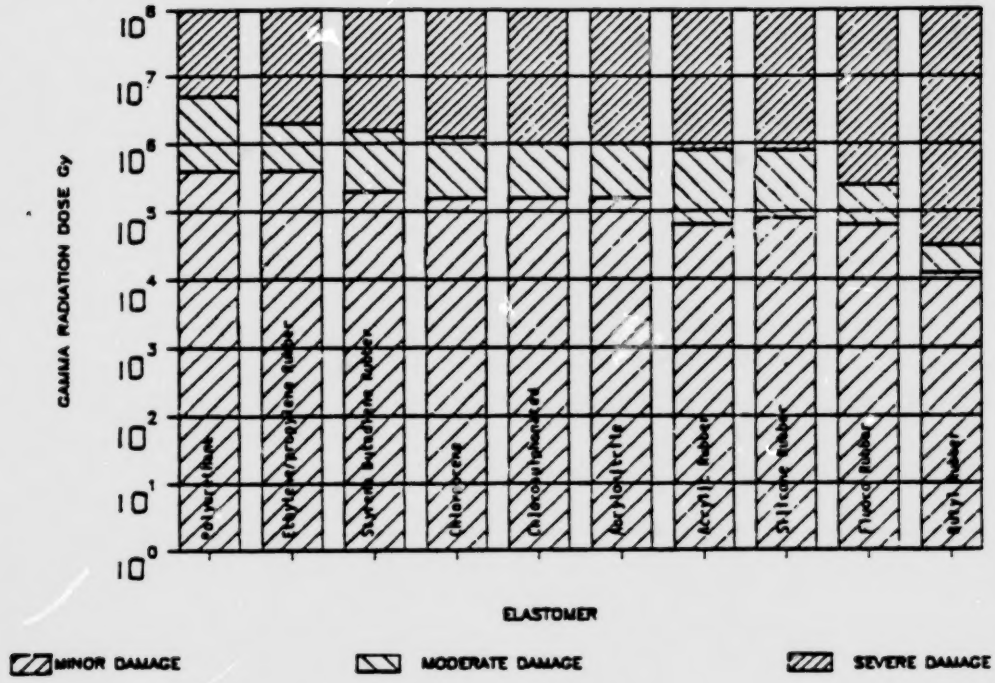


Figure 2: Relative radiation effects (to be used as guidelines). Atmosphere and other environmental conditions, such as temperature and dose rate, are not taken into consideration.

ASTM D2953 "Classification System for Polymeric Materials for Service in Ionizing Radiation" classifies polymeric materials based on their ability to withstand gamma radiation. Elastomers form Type 5 of materials and are classified into five classes. Other classes are rigid, non-load bearing low impact, rigid non-load bearing, high impact, load bearing flexible, inelastic, and materials for electrical applications.

Table 2: Type 5 Materials - Flexible Materials - Elastic, From ASTM D2953

Rating	Dose, rads	Properties After Irradiation[a]						
		Tensile Strength			Ultimate Elongation			
		Actual Value		Fraction of Original Retained, %	Actual Value, m/m (in./in.)	Fraction of Original Retained, %	Compression Set, %	Elastic Modulus, Multiple of Original
		MN/m²	psi					
Class 1	5×10^6	<8.3	<1200	<80	<2.5	<70	>40	...
Class 2	5×10^6	>8.3	>1200	>80	>2.5	>70	≤40	≤1.4
	10^7	>6.9	>1000	>60	>2.0	>50	≤50	≤1.7
Class 3	2×10^7	>10.3	>1500	>80	>2.0	>60	≤50	≤1.6
	5×10^7	>8.3	>1200	>60	>0.7	>40	≤70	≤2.0
Class 4	10^8	>10.3	>1500	>70	>1.3	>50	≤60	≤1.6
	3×10^8	>8.3	>1200	>50	>0.5	>30	≤80	≤2.0
Class 5	10^9	>8.3	>1200	>40	>1.0	>50	≤70	≤2.0
	3×10^9	>5.5	>800	>40	>0.5	>30	≤90	≤3.0

[a] Prepared and cured in accordance with Methods D 15, Compound and Sample Preparation for Physical Testing of Rubber Products." Curing time adjusted to give "optimum cure" for tensile properties. Materials filled with carbon black will not qualify for 5 mills.

In most cases, at the equivalent doses, low dose rates are more damaging than high ones. One of the plausible explanations is that oxidative degradation plays an important role and is limited by the rate of oxygen diffusion into the elastomer. That mechanism is consistent with results obtained for silicone - degradation appears to be independent of the dose rate. Silicones are known for their high transmittance of oxygen and therefore, unlike other elastomers, oxygen diffusion is not a rate limiting factor. [Ref. 11]

In order to conduct a meaningful accelerated aging of elastomers at high radiation dose rates, the rate controlling oxygen diffusion effect has to be eliminated. Results of irradiation of samples placed in oxygen under elevated pressure indicate that this approach eliminates dose rate dependence and therefore may form a basis for accelerated testing based on total radiation dose only. [Ref. 12]

2.6.2 Effect of the Dose Rate

In order to evaluate long term radiation effects on the properties of the elastomers, accelerated tests are often carried out utilizing high radiation rates to achieve desired total dose in a short time. It is now being realized that this approach might be misleading - degree of degradation is not only a function of the total dose but also that of a dose rate. [Ref. 13 and 14]

2.7 Summary

The three generic types of elastomers most widely used in CANDU pressure boundary service are chloroprene (Neoprene), EPDM and silicone. Silicones have generally better high temperature, radiation and ozone resistance than the other two elastomers but also have rather poor mechanical stress properties such as tensile and tear strength and abrasion resistance. As is emphasized earlier in this report, within each of those classes of materials a broad range of properties may be obtained on specific formulation.

In designing a given component the designer has to reply on his or his supplier's previous experience with the compound and its durability in the same or similar application and on a properly designed and executed test program.

Table 3: Resistance of Generic Types of Elastomers to Environmental Conditions (Ref. 9)

ELASTOMER	AGENT											
	Aliphatic Hydrocarbon	Aromatic Hydrocarbon	Inorganic Acids		Bases		Oxidizing Acids		Steam	Oils	Ozone	Radiation
			Conc	Diluted	Conc.	Diluted	Conc.	Diluted				
Acrylic	Ex.	Poor	Poor	Fair	Poor	Good	Poor	Poor	Poor	Good	Fair	--
Butadiene	Poor	Poor	Fair	Good	Fair	Good	Poor	Poor	Poor	Poor	Poor	Poor
Butyl	Poor	Poor	Good	Good	Fair	Good	Poor	Fair	Fair	Good	Good	Poor
Chloroprene	Good	Poor	Good	Ex.	Good	Ex.	Poor	Fair	Poor	Good	Good	Good
Chloro-sulfonated Polyethylene	Good	Poor	Good	Ex.	Ex.	Ex.	Poor	Good	Poor	Poor	Ex.	Very good
Ethylene Propylene	Poor	Poor	Good	Ex.	Ex.	Ex.	Poor	Fair	Fair	Poor	Ex.	Good
Ethylene Propylene-Diene	Poor	Poor	Good	Ex.	Ex.	Ex.	Poor	Fair	Fair	Poor	Ex.	Good
Isoprene	Poor	Poor	Fair	Good	Fair	Good	Poor	Poor	Poor	Poor	Ex.	Fair
Natural Rubber	Poor	Poor	Fair	Good	Poor	Good	Poor	Poor	Poor	Poor	Ex.	Fair
Nitrile	Good	Poor	Fair	Good	Poor	Fair	Poor	Poor	Poor	Ex.	Poor	Fair
Polysulfide	Ex	Good	Poor	Ex.	Good	Ex.	Poor	Poor	Ex.	Ex.	Ex.	Fair
Silicone	Fair	Fair	Good	Ex.	Good	Ex.	Poor	Ex.	Poor	Good	Ex.	Fair-Ex.
Styrene Butadiene	Poor	Poor	Fair	Good	Fair	Good	Poor	Poor	Poor	Poor	Poor	Good
Urethane	Fair	Poor	Poor	Fair	Poor	Good	Poor	Poor	Poor	Good	Ex.	Good

C. AGING OF ELASTOMERS IN CANDU PRESSURE BOUNDARY SERVICE

1. Vacuum Building Roof Seal

1.1 General

Multi-unit stations owned and operated by Ontario Hydro each have a vacuum building. The containment envelope for Pickering consists of the vacuum building, 8 reactor buildings interconnected by the pressure relief duct, and 12 pressure relief valves which are installed in the pressure relief duct and connected to the vacuum building by individual vacuum ducts. At both Bruce A and Bruce B, four reactor buildings tie into the vacuum building via 16 pressure relief valves.

The vacuum building is a reinforced concrete structure, which is in two sections at Pickering and Bruce - the perimeter wall and the roof slab. At Darlington the roof and walls are integral. The perimeter wall, roof and floor slabs form an airtight vessel. In the event of a LOCA (Loss of Coolant Accident) the steam and gas released in the reactor building will travel via the pressure relief duct and the pressure relief valves into the vacuum building. There the free space and pressure actuated water spray serve as a heat sink to absorb energy and reduce pressure. During normal operation, internal pressure in the vacuum building is between 6.9 and 27 kPa(a) (1 to 4 psia.)

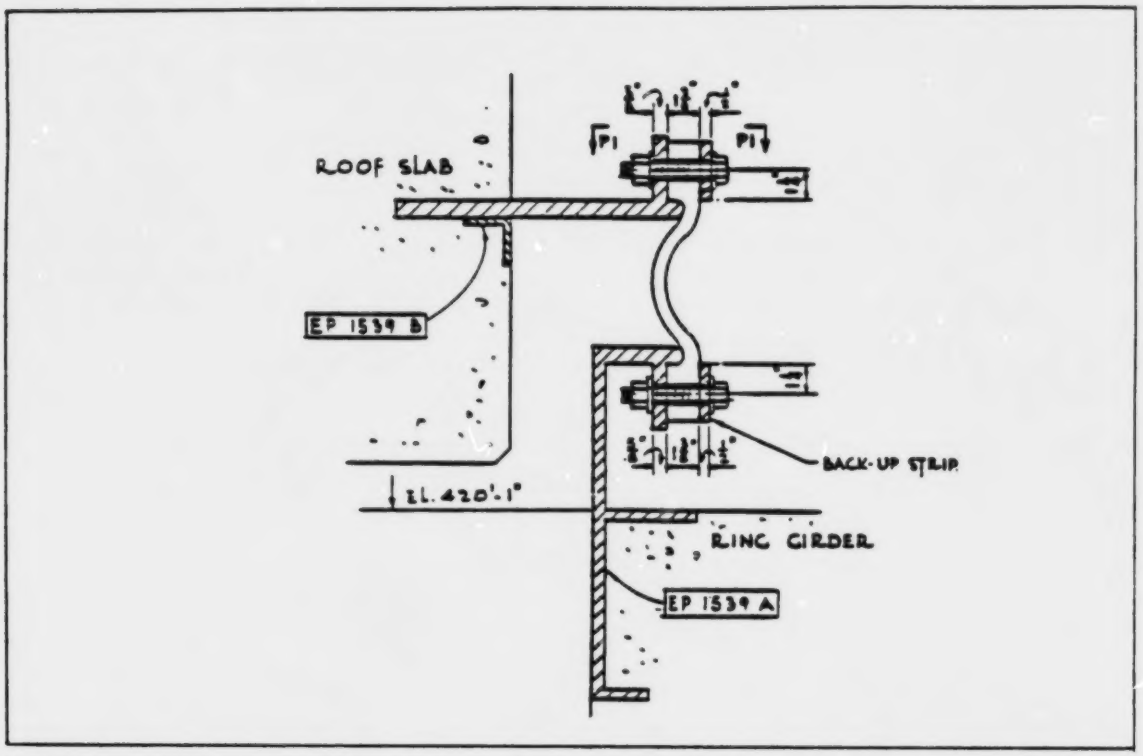
At Bruce A and B, the vacuum building roof seal is a 24 inch wide EPDM seal, held against the seal supports by 16 hoops of high strength steel tendons. The seals are protected from the elements by removable aluminium roof seal covers. Seal strips exist between the cover joints.

At Bruce, two continuous grooves on the back face of the seal match the ribs i.e. positioning bars, on the support steel, and anchor the seal against slippage. A post tensioning system which includes 4 anchor blocks is used to ensure constant and evenly distributed pressure on the rubber seal for positive anchorage and leak tightness. [Ref. 15)

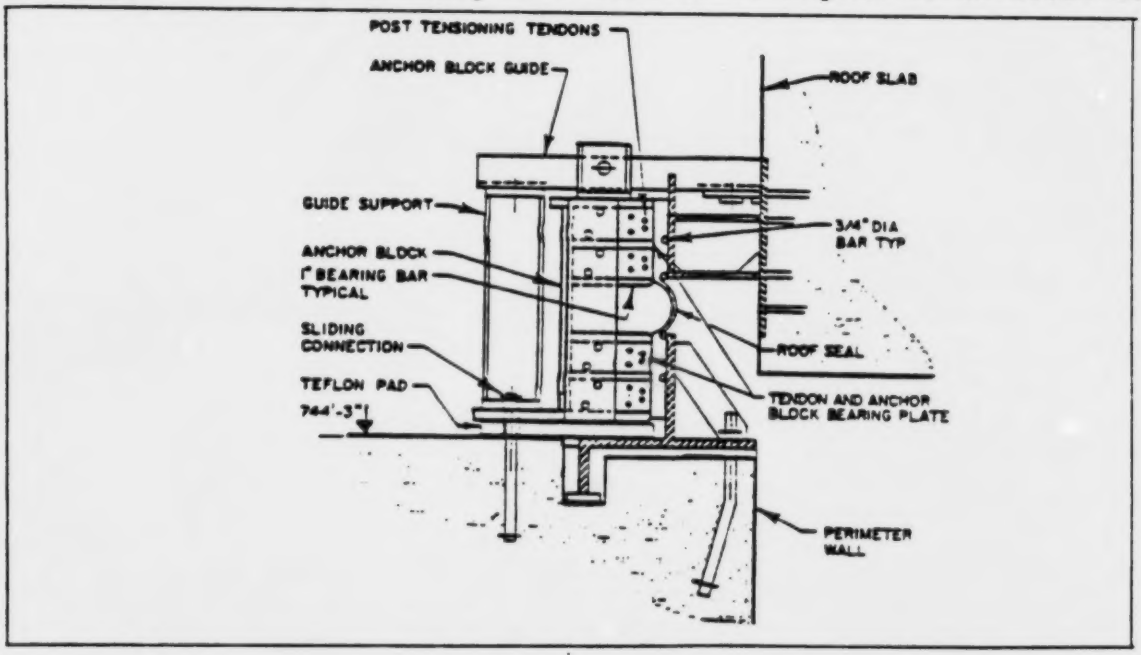
Refer to Figure 3 for sketches of the vacuum building seals at Pickering and Bruce.

1.1.1 Functional Requirements

The vacuum building roof seal forms a containment boundary and joins the walls and roof slab to allow for independent movement of the roof and internal structure relative to the walls. It retains vacuum inside the vacuum building, and can withstand post LOCA conditions of temperature and pressure.



Pickering NGS Vacuum Building Roof Seal (Ref. Dwg.NA-44-CG-25100-1006)



Bruce NGS Vacuum Building Roof Seal at Post Tensioning Anchor Blocks (Ref. Ontario Hydro Report 85-127)

Figure 3: Vacuum Building Roof Seals

A result of failure of this seal is that the attached reactor units have to be shut down, since seal failure represents a loss of integrity of the Negative Pressure Containment System.

1.1.2 Material

Pickering drawings of the vacuum building seal reference specifications L539 and L510-67, which are both Ontario Hydro specifications. These have been displaced by the specification for the replacement seal, which is in Appendix 1.2. The original vacuum building roof seal material is Neoprene, with fabric reinforcement, and was supplied by Dunlop.

The Bruce vacuum building roof seal was originally specified as a fabric reinforced Silicone rubber compound, to increase tensile properties and withstand radiation, high humidity and ozone. [Ref. 16]

However, the material supplied was EPDM (Ethylene Propylene Dieme Monomer), for both Bruce A and Bruce B. The manufacturer was Uniroyal.

The replacement seals for Pickering, Bruce A and Bruce B are a Silicone rubber as recommended by Armet, the supplier. The fabric is centrally located within the seal, and the edge of the fabric is to be covered with a minimum of 3mm rubber to protect the fabric. Operating conditions are not normally very severe. The pressure of tensile stresses makes resistance to ozone very important. In this respect Silicone is very good, and better than EPDM or Neoprene. A roof seal of silicone rubber which is correctly formulated and carefully installed, will meet the requirements of the current specification.

1.2 Technical Requirements and Specifications

CSA Standard N287.2 Material Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants, is applicable, since the vacuum building roof seal is a flexible joint acting as a containment boundary. This CSA standard specifies certain minimum material and test requirements that materials must meet. The relevant sections of this Standard are in Appendix B.

The specification for vacuum building roof seals is the most comprehensive specifications for elastomers in CANDU nuclear power plants. Standard ASTM test procedures have been complemented by test procedures meant to evaluate critical aspects of seal performance. Simulated post-LOCA performance is also tested.

The replacement vacuum building roof seal specification is concerned with the following properties of the seal:

- mechanical integrity
  . seal strength
  . tensile strength of an elastomer
  . strength of spliced joints (splice efficiency)
  . tear resistance
  . stability under attachment load

- creep and stress relaxation
  . retention of sealing backforce
  . creep under vacuum load

-degradation
  . resistance to radiation
  . resistance to steam
  . ozone resistance
  . stability under vacuum (aging in vacuum environment)

The specification is included in Appendix 1.1.

When compared to CSA Standard N287-M82, the Ontario Hydro Specification for the vacuum building roof seal is much more specific, and most of the test conditions are more severe. Tensile strength and tear resistance are the same in both specifications. Tensile strength of the fabric, and fabric/rubber adhesion are specified by the CSA Standard but not by Ontario Hydro. Heat aging is conducted at 70°C for 28 days in the CSA specification and for 7 days at 125°C in the Ontario Hydro specification. The latter is a more severe test.

1.2.1 Manufacturer Testing

Although CSA N287.2 on non-metallic liners and joint sealants is not specifically aimed at vacuum building seals, many of the test requirements are applicable, since the vacuum building roof seal is in effect a joint sealant.

Seal performance requirements, as specified by Ontario Hydro for the replacement vacuum building roof seals are listed in the vacuum building replacement roof seal specification.

Testing of the replacement vacuum building roof seals is on-going, and is being done by Ontario Research Foundation for Armet, the manufacturer.

1.3 Operational and Environmental Stressors

Design information for the Bruce vacuum building describes the environmental conditions that the vacuum building roof seal is subjected to as follows: [Ref. 17]

Pre-operational	Temp, interior:	2 to 21°C (35 to 70°F)
	exterior:	-7 to 29°C (20 to 84°F)
	Humidity:	atmospheric
Operational	Temp, interior:	2 to 21°C (35 to 70°F)
	exterior:	-7 to 29°C (20 to 84°F)
	Humidity, interior:	100%
Post-LOCA	Temp, interior:	176°C (256°F) for 10 secs. 49°C (120°F) for long term
	exterior:	-7 to 29°C (20 to 84°F)
	Humidity, interior:	100%

Maximum Positive Pressure: 55 kPag (8 psig)
Vacuum Pressure: -101 kPag (-14.7 psig)
Integrated Radiation Exposure: 1.1×10^5 Gy (1.1×10^7 rad)

Actual operational environmental conditions are much as specified in the design information, although the exterior temperature may well drop below -7°C (20°F) for short periods during the winter.

The vacuum building roof seals are exposed to atmospheric levels of ozone, which, in combination with mechanical stress, may cause cracking. Environment Canada states that the average annual ozone levels at Huron Park are 30 to 40 ppb, with levels as high as 124 ppb. Ozone concentrations greater than 100 ppb have a detrimental effect on elastomers. [Ref. 18]

Mechanical stresses are:

- compression due to attachment
- tensile stress due to the vacuum
- stresses due to movement of walls relative to roof

The mechanical stresses can be minimized by careful installation, and generally, atmospheric conditions are the major stressor during normal operation.

1.4 Operational Testing

CSA Standard N287.7 In-service Examination and Testing Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants (April, 1980) calls for examination and/or testing of organic parts of containment at least once/year.

Pickering

At Pickering, Vacuum Building Inspection Test 45 (now called Test C-9) has an intended frequency of once/shift, i.e. thrice/day. [Ref. 19] This is a detailed monitoring program, which includes monitoring vacuum pump operating times, main volume and upper chamber pressures. These tests would all detect vacuum building seal failure, but inspection of the actual seal is not included. Actual frequencies of testing are listed in Appendix 1.2, and indicate a very good record. Inspection of the seal seems to be done only when the concrete of the vacuum building is inspected, i.e. once every five years. The roof seal was inspected in 1972, 1979, 1980 and will be partially inspected in 1987. In view of the importance of the roof seal, more frequent inspection is recommended to detect deterioration before failure, such as the yearly inspection frequency recommended in CSA Standard N287.7.

Bruce A

The vacuum building leak rate test (Test 4.17) has an intended frequency of once/month. Actual testing frequencies are listed in Appendix 1.2 and have been about once/month since 1980. The Quarterly Technical Reports indicate that the roof seal was not initially inspected on an annual basis, but subsequent to the 1981 repair of the splice and tendon replacement, inspections were done on an annual basis. Since the Bruce B vacuum building seal failure, seals have been inspected initially three times/year, and now twice/year at both Bruce A and Bruce B.

Bruce B

The suggested testing schedule for the vacuum building leak rate test at Bruce B is once/week, as described in Test 4.21. The record of test completion is good.

Vacuum building roof seal inspection is done twice per year, because of the early problems with tendons and the 1985 seal failure.

Control room monitoring of vacuum building pressure provides a sensitive indication of seal performance, but the seal fabric can give way very suddenly, so this will not provide advance warning. If the sealing of the seal is imperfect, pressure readings would give an indication of leakage.

The best technique for inspection is a very careful and complete visual examination, and where cracks exist to use rubber replication to ensure that the defects are not becoming worse. Surface irregularities should be looked for, since they may indicate fabric failure. Hardness is not a good indication of seal deterioration, and there is no known method of measuring fabric tension.

1.5 Operational Experience

1.5.1 Summary of Failure Modes and Causes

Pickering

No major difficulties have been experienced with the vacuum building roof seal at Pickering. Minor cracks in the Neoprene roof seal were noticed in the 1979 inspection, and these are likely caused by exposure to ozone and changes in ambient temperatures. [Ref. 20]

Bruce A

The 1981 vacuum building roof seal inspection revealed that four of the 16 tendons which hold the seal in place were broken. Cracks were found in the cover rubber, at the splice. The cracks were wide and deep, extending into the body of the splice to expose the underlying rubber-coated fabric scab. The bond between this fabric scab and seal fabric provides the strength for the splice, so the damage had to be repaired as soon as possible. The cracks were attributed, by Ontario Hydro Research, to atmospheric ozone, combined with the high level of strain on the seal, at this location. Nicks in the surface of the seal were attrituted to mechanical impact during installation and removal of the roof shields. [Ref. 21]

Ontario Belting inspected the splice, and concluded that the splice deterioration was caused by overheating of the splice when it was made. The seal material, EPDM, is classified as having outstanding ozone resistance, but the cover rubber (which was the splice material) was #10 9330 STK, Butyl rubber which does not have as good a resistance to ozone.

Additional inspections of the roof seal were made in April and May, 1985, using fibre-optics, photography and rubber replication techniques. Defects were found in the north and south anchor blocks, consisting of cracks, but these did not appear to affect the strength-giving inner fabric. Seven major defect areas were identified, and all but one were associated with what appeared to be patches that had been applied to the seal prior to its installation. In most cases a tearing phenomenon was observed at the ends of the patches. The tears were shallow, extending no more than 2 mm into the material. The tears appeared to have flat bottoms, and no fabric reinforcing was visible. Delamination was observed at the edges of the patches. The one defect not associated with a patch consisted of three small holes in the surface of the seal, with an apparent depth of about 3 mm. [Ref. 22]

The Quarterly Technical Reports indicate that inspections of the vacuum building roof seal in 1986 revealed widening, but not deepening, of the flaws. This reoccured in 1987, and has been attributed to cold winter temperatures.

Bruce B

In March, 1985, after one year in service, the vacuum building roof seal at Bruce B failed, at a location directly behind the west tendon anchor block.

The Level 1 impairment of negative pressure containment resulted in Unit 5 and Unit 6 having to be shut down in a controlled manner. The tear in the seal at the west anchor block was an 'L' shaped tear, about 4 inches long vertically, and 25 inches long circumferentially. Similar damage was found at the north and east anchor blocks. Ontario Hydro has determined that the seal failure was caused by a combination of factors, including design and manufacture of the anchor blocks, and lack of adhesion between the nylon reinforcing fabric and the EPDM. The seal clamping did not allow movement between the roof and wall, (caused by temperature changes, for example) without fretting of the seal. The fretting caused the cracks. No aging of the seal was apparent. At Bruce A, the same clamping arrangement has resulted in cracks, but not a seal failure. The difference is attributable to differences in installation. [Ref. 23]

The major cause of the vacuum building roof seal failure was the poor design and manufacture of the anchor blocks. Ontario Hydro acknowledges a breakdown in the quality control and inspection of the anchors, and this is not likely to recur. [Ref. 24] Steps being taken to prevent another vacuum building roof seal failure include replacement of the seal with a new material, redesign of the post-tensioning system, and increased frequency of inspection.

1.5.2 Frequency of Failures

Generally, damage to the seals is due to lack of extreme care in handling, installation, inspection and repair i.e. some knife cuts were made to the Bruce B seal during its repair. [Ref. 25]

As noted above, in Section 1.5.1, there has only been one vacuum building roof seal failure. However, since a failure of the seal results in a loss of integrity of the Negative Pressure Containment System, all attached reactor units have to be shutdown, and this has a major economic impact for the utility.

1.5.3 Methods of Detection

Detection of possible impending failure has been provided only by visual inspection. As mentioned in Section 1.4, this is the only currently known method.

Optical and rubber replication techniques have been used to determine the extent of crack propagation rate. This is an effective method of determining if the material is deteriorating with time. Rubber replication provides a negative replica of the defect area, with dimensional accuracies in the order of 0.05 mm. [Ref. 26] Experience to date indicates that existing cracks become wider in winter, attributable to cold winter temperatures, and return to their former size in summer months.

Detection of the actual vacuum building roof seal failure at Bruce B was provided very rapidly by the Vacuum Building high pressure alarm.

1.5.4 Maintenance Actions

Pickering A

No remedial action has been taken at Pickering to repair the vacuum building roof seal cracks, since they are relatively minor.

Bruce A

Repair of the vacuum building roof seal splice in 1981 was done by Armet, who is the supplier of the replacement vacuum building seals. Some difficulty was encountered in finding a material which would bind to the EPDM seal, and eventually a Neoprene based adhesive/sealant developed by 3M was used. [Ref. 27] The splice was reinforced, and supported.

The vacuum building roof seal was re-inspected in 1983 and 1984, and found in good condition. Traces of animals chewing the rubber seal were found in 1984. A screen mesh was placed over ventilation openings in the roof cover, to prevent animal ingress.

Bruce B

The tear in the vacuum building roof seal at the west anchor block was repaired by hot splicing in a new section of seal. Hot vulcanized patches were used to repair damage at the north and east anchor blocks, and a cold patch was applied at the south block. The seal was reinstalled. Positive and negative leak tests were conducted to prove the integrity of the repaired seal. The vacuum building was returned to service March 12th, after an 11 day forced outage. [Ref. 28]

The anchor blocks have been modified to allow for some movement of the roof, without shearing of the seal.

1.5.5 Modifications Resulting from Failures

Pickering A

Following the vacuum building roof seal leak at Bruce B on March 1, 1985, the design of the Pickering vacuum building seal was reviewed. Pickering design does not include the components which initiated the leak at Bruce B, i.e. the lug and bar; and is thus not subject to the same failure mode. The seal clamping at Pickering is very simple, compared to that used at Bruce, as shown in the diagrams in Figure 3.

Bruce A

A review of the vacuum building roof seal and attachment design was done, and it was concluded that gross failure of the repaired splice was not likely after a LOCA, and anticipated releases after a LOCA would be much lower than allowed. No further modifications were made at the time. However, a new vacuum building roof seal of Silicone rubber was installed in the 1987 station outage, along with modified anchor blocks.

Bruce B

In early 1986, control room monitoring was installed for vacuum building chamber pressures. The intent is to provide early warning of impending seal leakage.

Ontario Hydro Research has done extensive work on the seal, and inspections were made initially three times/year, and are now made twice/year. Ontario Hydro will be replacing all vacuum building seals, and an extensive testing program of the replacement seal has been specified. (Refer to Appendix 1.1)

1.6 Recommended Guidelines for Monitoring Methods and Maintenance

(a) All personnel handling the seals must be made aware of the extreme care required during handling, installation and repair of the seal, by a thorough briefing prior to handling or installation.

(b) More frequent visual inspection of the vacuum building roof seal on a regular basis is recommended for Pickering. Yearly inspection, as required by CSA N287.7, would be adequate.

(c) Results of each examination of the seals, using rubber replication where needed, should be well documented and filed at the appropriate generating station, and possibly with the AECB. A statement of assurance of the seal integrity should be included, and should have the concurrence of the appropriate utility Design or Research Department.

Suggestions

To reduce cracking caused by high atmospheric ozone levels, it may be feasible to purge the space above the seal, with dry warm air, for example, and thereby, reduce the ozone concentration of air in contact with the seal. This would also reduce corrosion of the retaining tendons. Also, in view of the importance of the vacuum building roof seal, consideration should be given to the development and installation of transducers, which would measure the sealing force on the vacuum building roof seal, and alarm in the control room on low levels.

2. Pressure Relief Duct Seals

Pressure relief ducts and the associated vacuum buildings exist only at Pickering A & B, Bruce A, Bruce B, and Darlington.

There are four seals in the pressure relief duct. These are:

2.1 Airlock Seals
2.2 Pressure Relief Valve Components
2.3 Bulkhead Panel Components
2.4 Expansion joints

The bulkhead panels and pressure relief duct expansion joints exist only at Pickering A and B.

2.1. Airlocks

2.1.1 General

There is essentially no difference between the pressure relief duct airlocks, and the airlocks found elsewhere in the stations. For Pickering A and B the pressure relief duct airlocks AL1, AL2 and AL3 are common to all 8 units. The equipment airlock AL2, with associated personnel airlock AL1 is located on the north wall of the duct, just east of Unit 2. Airlock AL3 is located on the north wall of the duct, just east of Unit 7. Refer to Figure 4 - Airlock Schematic.

The equipment airlock is required to provide the means for transfer of the pressure relief valves across the containment boundary (i.e. transporting the valves into or out of the pressure relief duct).

At Bruce there are six transfer chambers and seven airlocks associated with the pressure relief duct, but the design is quite different from Pickering, in that the pressure relief duct runs underneath the attached reactor buildings, rather than alongside and above ground. Also, the pressure relief ducts at the Bruce stations serve as the passageway for the fuelling machines.

2.1.1.1 Functional Requirements

The function of the inflatable seals, which are inflated with instrument air, and the perimeter seals, is to prevent gas leakage past airlocks and containment doors. The differential pressure across the seal is normally very low, i.e. a couple of inches of water, but may reach 83 kPag (12 psig) at the Bruce stations, and 124 kPag (18 psig) at CANDU 600s during emergency conditions.

2.1.1.2 Material

The original specification for Pickering A airlocks, AECL

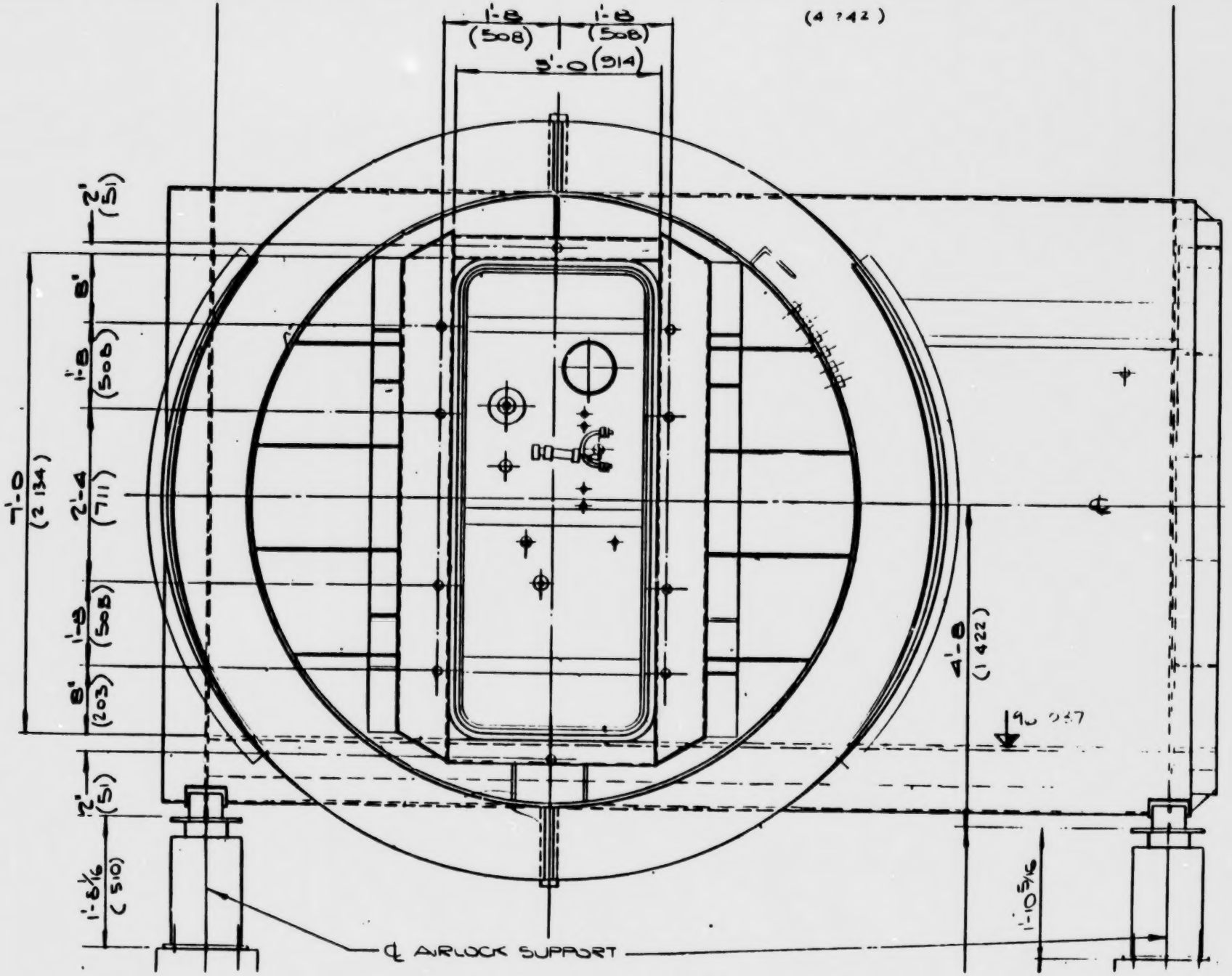


Figure 4: Reactor Building Personnel Airlock (Ref. AECL Dwg.79-21601-7552-01-GA-E)

Specification NP-E-779, calls for inflatable type ozone resistant rubber or Neoprene seals. [Ref. 30]

Neoprene seals were used originally at Pickering and Douglas Point, but were replaced with Silicone seals in about 1972, due to the relatively short life of the Neoprene seals.

Ontario Hydro Specification L-625SM-82 is much more specific - it calls for red phenyl type Silicone rubber. This specification is used for airlock seals at all Ontario Hydro stations. Specification L-625SM-82 is included in Appendix 3.1.

Silicone is a more appropriate material for the airlock seals then Neoprene, since it has better retention of elasticity at low temperatures, which the airlock seals are exposed to during winter months. The applicable standards and regulations are not material specific, so the Ontario Hydro and AECL specifications are the most relevant documents in determining performance requirements.

2.1.2 Technical Requirements & Specifications

In the original specification for the Pickering pressure relief duct equipment airlock, all standards listed are for the airlocks and not specifically for the seals. [Ref. 31]

The current specification is used for procurement of all Ontario Hydro airlock seals, and the specified standards are: [Ref. 32]

OH Standard QA-31M, Standard Production Qualification Procedure.

CSA Z299.3, Quality Verification Program Requirements in addition to ASTM Standards, which specify testing procedures.

CSA Draft Standard N285.3, Requirements for Containment System Components in CANDU Nuclear Power Plants, states that inflatable non- metallic seals may be used for containment isolation (i.e. airlock seals) but that dual seals are required, and each must be supplied independently with piping and valving, so that if one seal fails, the other remains operational. Facilities are to be provided for pressurizing the space between the seals, for in-service testing of each seal pair. Pickering A and Bruce A do not have this capability, but Pickering B, Bruce B and Pt. Lepreau do. Non-metallic materials shall be qualified for the service conditions and the required service life, and the qualification method (i.e.test results) shall be documented.

This draft standard, when it comes effective, in conjunction with CSA N287.7, In-service Examination and Testing Requirements, will provide adequate standards for design, manufacture and testing of the seals.

2.1.2.1 Manufacturer Testing

The AECL Design Specification requires operational testing by the manufacturer on the airlock, to demonstrate proper operation of the doors, seals, interlock and other equipment. [Ref. 33]

Manufacturer testing of the seal is described in Section 3.2.1 of the report.

2.1.3 Operational and Environmental Stressors

For Pickering, the specified maximum differential pressure between the airlock and outside containment, or between the airlock and the pressure relief duct is -58 to 41 kPag (-8.5 to +6 psig). [Ref. 34] For Bruce A and B, the maximum differential pressure is specified as -48 to 83.7 kPag (-7 to 12 psig), and for CANDU 600s, only the maximum positive differential pressure is specified, as 124 kPag (18 psig). [Ref. 35]

Pickering design temperatures are: [Ref. 36]

Maximum outside temperature:	32°C (+90°F)
Minimum outside temperature:	-29°C (-20°F)
Maximum temperature inside Pressure relief duct and airlock:	110°C (+230°F), following a LOCA

Ozone levels for the pressure relief dust airlock seals are, low, i.e. atmospheric. Radiation levels are also negligible, i.e. background, unless a LOCA occurs. Usage of these airlocks is not frequent, due to their location, and wear and tear is minimal. Temperature extremes are probably the prevalent stressor, although there is a heater inside the airlock to reduce exposure to low temperatures. Low temperatures cause the seal to become brittle, and inflation/deflation become very difficult.

Since the airlocks and transfer chambers at Bruce are located very differently from Pickering, they are not exposed to external temperatures, and temperatures would probably not drop below 10°C.

Additional stressors are fatigue from cycling, i.e. inflation and deflation of the seal, abrasion of the seal during door movement, and damage caused by contact with sharp tools, for example.

2.1.4 Operational Testing

CSA N287.7 (April '80), In-service Examination and Testing Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants, requires that after the in-service date of the station, organic parts are examined/tested a

minimum of once every year, but the frequencies of examination/testing shall be increased for components which have exhibited significant deterioration and which may warrant future repair or replacement. Design Manual DM44-21130 for Pickering A states that all airlocks are subjected to operational, pressure and leakage tests on an annual basis, as per Operating Manual 0-21130. Additionally, Test C-8, Airlock Inspection, is on a routine test schedule, and is done once/shift. (See Section 3.4 for further details for both these tests).

For Pickering B, Test C-21, Airlock Inspection, is on a routine test schedule, and is done once/shift. (See Section 3.4 for further details).

At Bruce A and B, two tests are done on the airlocks and seals. The airlock pressure test (leak rate test) is done once/year, and measures the airlock leak tightness. The seal leak rate test measures the rate of depressurization of the seals, and is scheduled to be done twice/year.

Airlocks are instrumented, as described in Section 3.3. Detection of failures is rapid, and adequate. Failure of one seal does not have major consequences, because of the seal redundancy, and the pressure relief duct airlocks are not frequently used, so inspection is also adequate.

For inspection record of airlocks, see Appendix 3.2.

2.1.5 Operational Experience

2.1.5.1 Summary of Failure Modes and Causes

The pressure relief duct airlock seals experience the same stressors as the other airlock seals, but the effect of low ambient temperatures aggravate this situation at Pickering. The failure modes and causes are described in Section 3.5.1, for all airlock seals.

2.1.5.2 Frequency Failure

One or two failures of seals/year occur, but so far have not caused any airlock unavailability, which is defined as the fraction of time that an airlock is unavailable to perform its intended function. A record of failures, extracted from the Quarterly Technical Reports, is contained in Appendix 2.1.

2.1.5.3 Methods of Detection

Detection of failure is either visual, i.e. noticed during an inspection, or provided by the airlock instrumentation in the Control Room.

2.1.5.4 Maintenance Actions

Generally, replacement of the defective seals is done within a few hours of detection.

2.1.5.5 Modifications Resulting from Failures

The original Neoprene seals at Pickering were replaced with Silicone seals, since these have a higher tolerance to low temperatures.

Also, heaters were installed at these airlocks, so that ambient temperatures would not be as extreme.

The air supply to each airlock was duplicated in 1979, to reduce the chances of seal failure due to lack of air supply.

Numerous other changes have been made, e.g. improving the reliability of the air supply valves, and airlock trouble annunciation, which do not directly affect the elastomeric seal.

2.1.6 Recommended Guidelines for Monitoring Methods and Maintenance

For the pressure relief duct airlocks, which are infrequently used, inspection and testing frequencies are adequate, as are maintenance actions.

2.2 Pressure Relief Valve Components

2.2.1 General

There are very large pressure relief valves in the valve header surrounding each vacuum building, at Pickering, Bruce A, Bruce B, and Darlington. These valves are normally closed, and provide isolation between the interior of the vacuum building and the pressure relief duct. In the event of a LOCA, these valves allow the steam released by the accident to escape into the vacuum building, where it expands and is doused. There are 12 pressure relief valves at Pickering, of which three (PRV -1 to -3) are instrumented and nine (PRV -4 to -12) are uninstrumented. The nine uninstrumented valves close by gravity when the pressure in the relief duct has dropped below the relief set point. The three instrumented pressure relief valves are automatically controlled to maintain the reactor building pressure slightly subatmospheric. There are 16 pressure relief valves at Bruce A, of which none are presently instrumented, but four will be instrumented by year-end 1987. At Bruce B there are 12 non-instrumented and 4 instrumented PRVs, and 16 at Darlington. Four of the pressure relief valves at Bruce are to become instrumented in early 1987. In addition, Bruce has four auxiliary pressure relief valves which are 36" pneumatic butterfly valves. Darlington uses two types of pressure relief valves, ten type I (Pickering A design) and 6 type II (almost identical to Bruce B valves).

2.2.1.1 Functional Requirements

The rolling upper and lower diaphragms are installed between the housing and the piston of the pressure relief valves. Their function is to seal the space between the piston and the cylinder, under the operating conditions described in Section 2.2.3. The O-rings and other components provide leak-free joints between various parts of the pressure relief valves.

2.2.1.2 Material

There are several elastomeric components of these valves, as shown in Figures 5 and 6. These are the upper and lower diaphragms, the seat seal, lower sealing ring and bumper ring. Ontario Hydro Technical Specifications L-591 for the Pickering pressure relief valves and L-592 for the Bruce pressure relief valves both call for pressure relief valve diaphragms of EPT (Ethylene Propylene Terpolymer). [Ref. 38 and Ref. 39]

The Darlington design calls for EPDM (Ethylene Propylene Diene Monomer) rolling diaphragms, with one sheet of Dacron Deno fabric reinforcement. [Ref. 40] The functional temperature range of the material is -54 to 150°C.

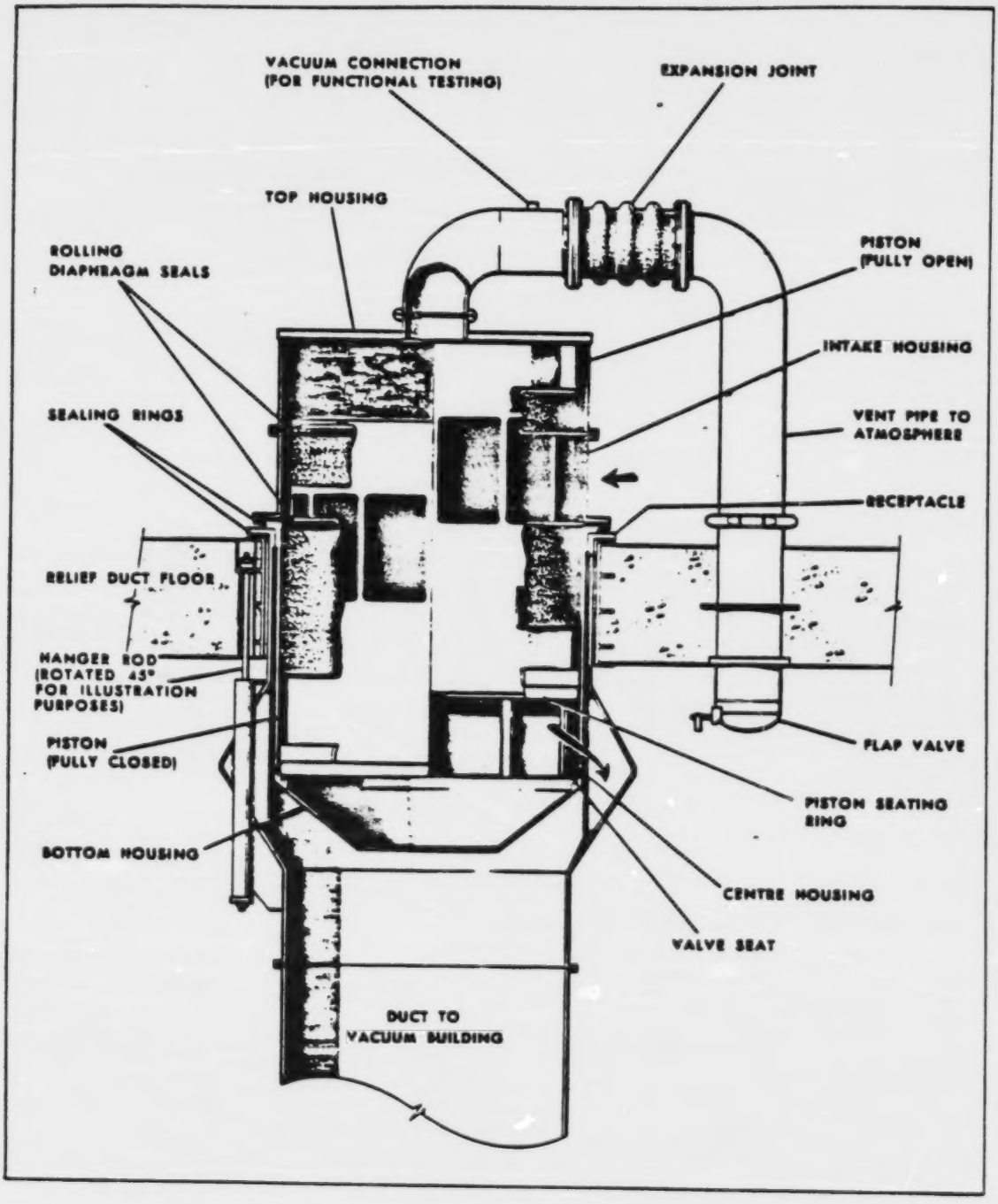


Figure 5: Type I Pressure Relief Valve to Vacuum Building
(Ref. AECL Design Manual 44-25200-4)

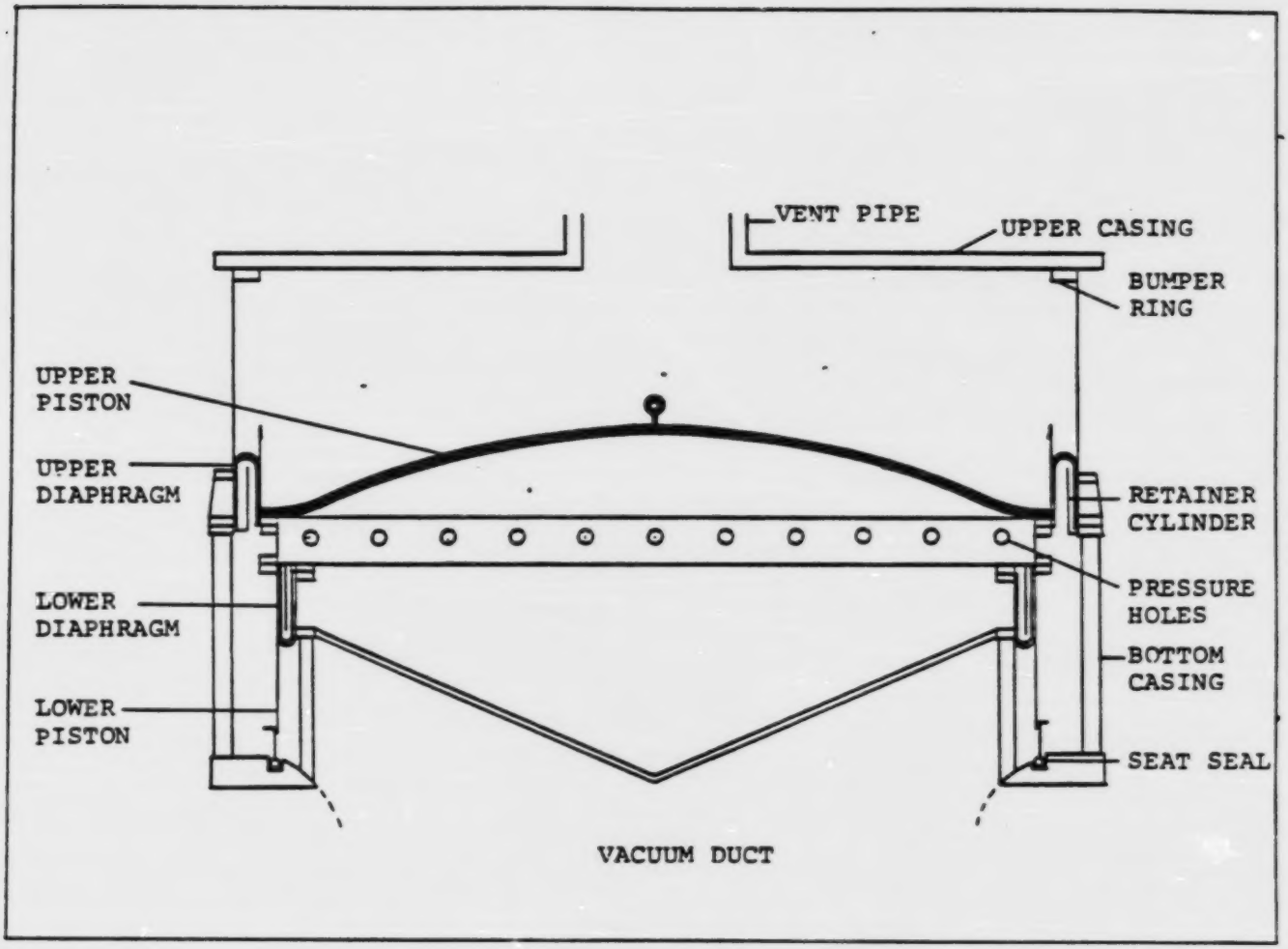


Figure 6: Schematic of Type II Pressure Relief Valve

During normal operation, temperature and pressure are at ambient conditions so a properly formulated EPDM elastomer should be able to perform adequately. The expected life can best be determined from actual operational experience, as described in Section 2.2.5.

The bumper ring, seat seal and lower sealing ring are Neoprene, since suitable shapes are more readily available in this material, and long life in perfect condition is not critical, since parts are relatively easy to replace.

2.2.2 Technical Requirements & Specifications

Specifications L-591-70 for Pickering and L-592-70 for Bruce are very similar and define basic elastomer properties. These include:

(1) ply adhesion
(2) stress relaxation
(3) ozone resistance
(4) tensile strength
(5) hardness

The specifications also include a relatively detailed material specification.

The material designation is 3BA525A14B13C12F17Z1Z2Z3Z4Z5, where:

3	Grade #3
B	Heat resistance. After aging at 100°C for 70 hours: Change in tensile strength < ±30 % Elongation < ±50% Change of hardness < ±15 points.
A	Volume swell: no requirements
5	Hardness: 50±5 points
25	tensile strength: 2500 psi more specifically:
A14	Heat resistance. More stringent classification than "B" viz after aging at 100°C for 70 hours: Change in tensile strength, max - 25% Change of hardness, max ±10 points
B13	Compression set, 22 hours at 70°C: max 25%
C12	Resistance to ozone, quality retention rating: min 85%
F17	Low temperature brittleness: non-brittle after 3 min at -40°C
Z1	ethylene propylene terpolymer
Z2	ozone test exposure of 48 hours minimum
Z3	T2 stiffness in environment not warmer than -18°C
Z4	Low temperature stress relaxation of 40% maximum
Z5	Ply adhesion of 30 lb/in/ply

The diaphragm specification does not include testing of the diaphragms under simulated operating conditions, although the material itself, if properly formulated, can readily withstand all anticipated operating conditions.

2.2.2.1 Manufacturer Testing

The Ontario Hydro specifications require that the diaphragms are leak tested, tested for ozone resistance, low temperature stress relaxation, seal strength, splice strength and flexibility force. The specification also requires the manufacturer to provide certified data to show adequate quality control of materials and manufacturing processes, and the results of the required tests.

2.2.3 Operational and Environmental Stressors

Environmental conditions are specified as follows for Darlington: [Ref. 41]:

Temperature:	Normal operation:	dry air @ 40°C (104°F)
	LOCA conditions:	maximum D_2O saturated air @ 100°C (212°F)
Ozone:		0.02 mg/L at standard atmospheric conditions
Radiation:		Insignificant, except in the event of a LOCA

Actual environmental conditions at Bruce are very similar to those specified for Darlington. Temperatures are monitored in the pressure relief valve manifold, and are normally around 20°C, even in mid-winter.

At Pickering, due to the different design of the pressure relief duct, temperatures may drop below freezing. Heaters are located directly under the pressure relief valve pipes, and some of the pipes are heat traced, so temperatures are relatively moderate.

Additional stresses are compression stress due to attachment of the diaphragm, and tensile and compression stresses of diaphragms during testing. These stressors, acting together, appear to be major at Bruce, as mentioned in Section 2.2.5. In addition, some cracking caused by exposure to ozone has been observed. [Ref. 42]

2.2.4 Operational Testing

CSA N287.7, In-service Examination and Testing Requirements for concrete containment structures for CANDU Nuclear Power Plants, requires yearly testing/examination of pressure relief valve diaphragms and O-rings.

AECL (Atomic Energy of Canada Limited) Specification 29-34210-1 for Bruce B specifies that a check on the rolling diaphragm hardness should be performed on a routine basis

every 10-14 months to measure the aging rate of the material. The diagram in Appendix 2.2.1 shows the unacceptable level of hardness, which is expected after 10 years service. The diaphragms should therefore be replaced after ten years service, provided hardness measurement readings do not exceed the unacceptable level before this, and no other damage is observed.

Pickering call-ups C-2 for the Instrumented Pressure Relief Valves and C-1 for the Uninstrumented Pressure Relief Valves are detailed tests, which include leak testing of the upper rolling diaphragm seal, the piston sealing ring and the lower seal. Any deficiencies noted during the test are to be reported, and corrective action taken. Hardness measurements of the diaphragms, which are an indication of aging, are not taken on a routine basis, but are taken occasionally.

In the early years of operation, i.e. 1972-1973, testing seems to have been a bit sporadic, with testing requirements of one valve/week. The testing frequency was changed to one valve/month in 1974, and the testing record has been very good, with testing reported as 100% complete from 1980-1985. Refer to Appendix 2.2.2 for record of testing.

Bruce A changed the testing frequency of pressure relief valves from 16 valves/year (i.e. each valve tested yearly) to four valves/year, in January 1986. The test, SST 4.8, includes a visual inspection of all elastomeric components, and a recording of the state of the diaphragm and valve seat.

In addition, Bruce A does a monthly main pressure relief valve inspection on all pressure relief valves, which includes checking the diaphragm position, but does not include a complete visual examination, and a yearly upper diaphragm hardness test, using a durometer. The maintenance manual states that a durometer hardness greater than 60 requires valve removal, dismantling, and a complete inspection of both diaphragms. [Ref. 43] Not all of the diaphragm is accessible, so the areas of the diaphragm which are the most highly stressed (i.e. bent surfaces) cannot be hardness tested. The seat seal hardness is also checked, and if the hardness reading is more than 10 durometer units greater than normal (30-40 Durometer), a complete strip down of valves and a seal replacement is required. All patching or vulcanizing is required to be done by the manufacturer.

Bruce B Test 4.11, on non-instrumented main pressure relief valves is scheduled to be done once/year, but testing frequency was changed to four valves/year. Bypass pressure relief valves are also checked once/month (Tests 4.14 and 4.15).

The design for Darlington requires each valve to be operated every 16 months, and a visual inspection to be done every 6 months. [Ref. 44] The allowed leakage through each valve is a maximum of 0.014 m^3/min (0.5 scfm) with the vacuum building at 7kPa(a) (1 psia) and the reactor building at atmospheric pressure.

2.2.5 Operational Experience

2.2.5.1 Summary of Failure Modes and Causes

At Pickering some cracking and loss of resilience of the diaphragms and the O-rings has been experienced over the years since operation began in 1971. This has been attributed to cold ambient temperatures, in spite of radiant heaters being installed in the relief duct. Hardening of elastomers often results in a concomitant shrinkage and loss of sealing force. This could cause the diaphragms to pull out from the clamping bands, which would cause a loss of function. All reported leakages have been either in the first or fourth quarter, i.e. the winter period. Refer to Appendix 2.2.3 for extracts from Quarterly Technical Reports.

At Bruce A, one incident of a torn diaphragm, hardening, and deterioration at the bolt holes in the diaphragm has been recorded. At the bolt holes in the upper diaphragm, the seal has flowed into the oval bolt holes in the retainer cylinders, and the resulting thinning of material around the bolt hole has caused the material to split. The retainer rings were an addition to the original design, as mentioned in Section 2.2.5.5. [Ref. 45]

The bolt holes were not equal distances from the edge of the seal, resulting in unequal stressing of the diaphragms. Splits in the diaphragms and gouges to 1/8" depth, presumably caused by rough handling during installation, as well as some lack of adhesion between seal and fabric, was also found. [Ref. 46]

Operating conditions at Bruce are very similar to those at Pickering, and the material is the same; but Bruce A has had more difficulties with their diaphragms. This is probably closely related to the differences in design of the pressure relief valves, and differences in maintenance and handling of the diaphragms.

2.2.5.2 Frequency of Failure

There are very few recorded replacements of diaphragm seals, twice at Pickering, and four times at Bruce. Unavailability of the pressure relief valves has been 0 at Pickering for the years 1978-1985, where unavailability is defined as the

fraction of time that a system or component is unavailable to perform its intended function. Unavailabilities for Bruce A and B pressure relief valves are recorded in Appendix 2.2.3.

2.2.5.3 Methods of Detection

Detection of failure is either visual or provided by failure of the leak rate test. The diaphragm hardness is monitored routinely at Bruce, but not at Pickering. No increase in hardness does not necessarily prove that a seal is satisfactory, i.e. it may be torn elsewhere, but it does indicate if the seal is no longer satisfactory.

Durometer readings are quite subjective, and vary with the pressure being applied. At Pickering, seal durometer hardness was observed to increase initially, i.e. hardness of diaphragms was 55 in 1970, and 76 (upper diaphragm) and 71 (lower diaphragm) in 1980. [Ref. 47] The rate of change has slowed down with time, since no hardness change was observed in 1984.

2.2.5.4 Maintenance Actions

Replacement of the diaphragms and O-rings is done soon after detection of failure. The maintenance department has occasionally repaired splits with rubber cement.

2.2.5.5 Modifications Resulting from Failures

In 1976, it was discovered that 11 out of 15 pressure relief valves at Bruce A had reversed diaphragms, caused by the negative pressure test. To prevent the reversal of the diaphragms, retainer rings were installed in 1979. The installation of these resulted in a large unavailability of the pressure relief valves for the year. The diaphragms at Pickering are scheduled to be changed in 1990, if a change is warranted. A specification is being prepared for these now.

2.2.6 Recommended Guidelines for Monitoring Methods and Maintenance

(a) Hardness measurements of the diaphragms should be taken on a regular basis, i.e. yearly. Although the diaphragm hardening observed at Pickering does not necessarily indicate impending failure, the difference in replacement procedure between Pickering and Bruce does not seem justified.

(b) A hardness criterion for replacement should also be established for Pickering.

(c) Fibre optic inspection may be a practical alternative to dismantling of the valve, for inspection of diaphragm surfaces. This should be investigated.

(d) For the Type I, Pickering pressure relief valves, the yearly inspection should also ensure that the diaphragms are not pulling out from under the clamping bands. This occurred during a pressure reversal test done on a Darlington Type I pressure relief valve by AECL-SPEL in 1984. Modifications to rectify this problem are planned for the vacuum building outage.

(e) For the Pickering diaphragms, it was determined in 1984 that since the original diaphragms and the replacement diaphragms in storage were not manufactured according to present specifications the replacements should not be used as 'permanent' replacements. [Refs. 48 and 49] In view of this, the new diaphragm specifications should be prepared as quickly as possible, and new replacement diaphragms procured.

2.3. Pressure Relief Duct Bulkheads

2.3.1 General

A pressure relief duct bulkhead exists only at Pickering A and B, not at Bruce. The pressure relief duct bulkhead is installed in the circular hole in each reactor building wall, between the boiler room and the pressure relief duct.

Pickering A has a bulkhead containing louvres and aluminium bursting panels, between the boiler room and the pressure relief duct.

The bulkhead consists of two sizes of panels, A and B, within a steel frame. A panel consists of two aluminum angle frames screwed back to back, with aluminum foil sandwiched between the two frames, and sealed to the frames with Dow Silastic 140RTV adhesive.

The panels are clamped to structural steel framing in the bulkhead by steel angles and clamps, and flat bars held together by Nelson studs. The clamps have elastomeric gaskets glued to them. The aluminium foil panels have a grid on the reactor building side to provide a greater pressure relief duct to reactor building burst pressure. [Ref. 51]

Pickering B has pressure relief duct bulkheads of a completely different design, and these also contain elastomeric seals. These seals form a pressure boundary between the reactor building and the pressure relief duct, but this is not a containment boundary.

The pressure relief duct bulkhead consists of two 2.5 cm (1 in) thick steel plates, 38 cm (15 in) apart, with 55 penetration pipes of 81.3 cm (32 in) diameter. The bulkhead is floating in the embedment with the help of a perimeter seal, 7.62 m (25 ft) in diameter. The perimeter seal is designed to seal off the leakage path around perimeter of bulkhead. It is installed by clamping rings between seal ring attachment of bulkhead and flange plate of embedded part, on the reactor building side only.

Within the bulkhead there are:

46 blow-out panels, open at differential pressure between the reactor building and pressure relief duct:	13.8 ± 1.7 kPad
Two drop panels, also release pressure from reactor building and remain open after activation	3.45 ± 0.60 kPad

Six blow-in panels, open at differential pressure between pressure relief duct and reactor building: 37.92 ± 3.45 kPad

One access door

Two 76.2 cm (30 in) isolation valves connected to the bulkhead in series with drop panels.

Two bypass valves/unit, which connect the reactor building to the pressure relief duct in case of a small increase in reactor building pressure <13.8 kPad (<2 psid), which is not enough to release the panels. These valves are 45.7 cm (18 in) butterfly valves, with Teflon diaphragms.

There are also perimeter seals around the blow-out and blow-in panels, the drop panel assembly, and the access door assembly, as well as bellow seals on the bulkhead pipe penetrations. [Ref. 52] Refer to Figures 7 and 8.

2.3.1.1 Functional Requirements

The pressure relief duct bulkhead controls the flow of air between each of the reactor buildings and the pressure relief duct. It allows minimal leakage of air during normal operation.

2.3.1.2 Material

At Pickering A, the panels contain gaskets of EPT, with a specified hardness of Durometer A50. There is a sealing gasket between the aluminum frames and the bulkhead frames which is EPT, closed cell sponge rubber ASTMD1056, grade SBE.41. It is 2.5 cm (1 in) wide, 0.64 cm (1/4 in) thick, and 58.4 x 63.5 cm (23 in x 25 in) for panel A or 58.4 x 155 cm (23 in x 61 in) for panel B.

The elastomeric bellows seals around the piping penetrations on the Pickering B bulkhead were originally installed as Silicone rubber, but these failed after three months, i.e. they lost all resilience to tearing. The compound used here was GE RTV 700 as was specified: [Ref. 53]

tensile strength:	4134 kPa (600 psi)
elongation:	400%
hardness:	30 ±5 A Durometer A
tear resistance:	27 kg_f/cm (150 lbs/in.)

The problem was tracked down to a change in the manufacturing process, and the seals were replaced with a urethane compound - Dupont Adiprene L-83. The bellow seals were manufactured in the AECL lab at Sheridan Park, using a polyol cure, and several additives. The 7.62 m (25 ft) perimeter seal was also originally Silicone, and was replaced by urethane. The manufacturer was Technimold, (a

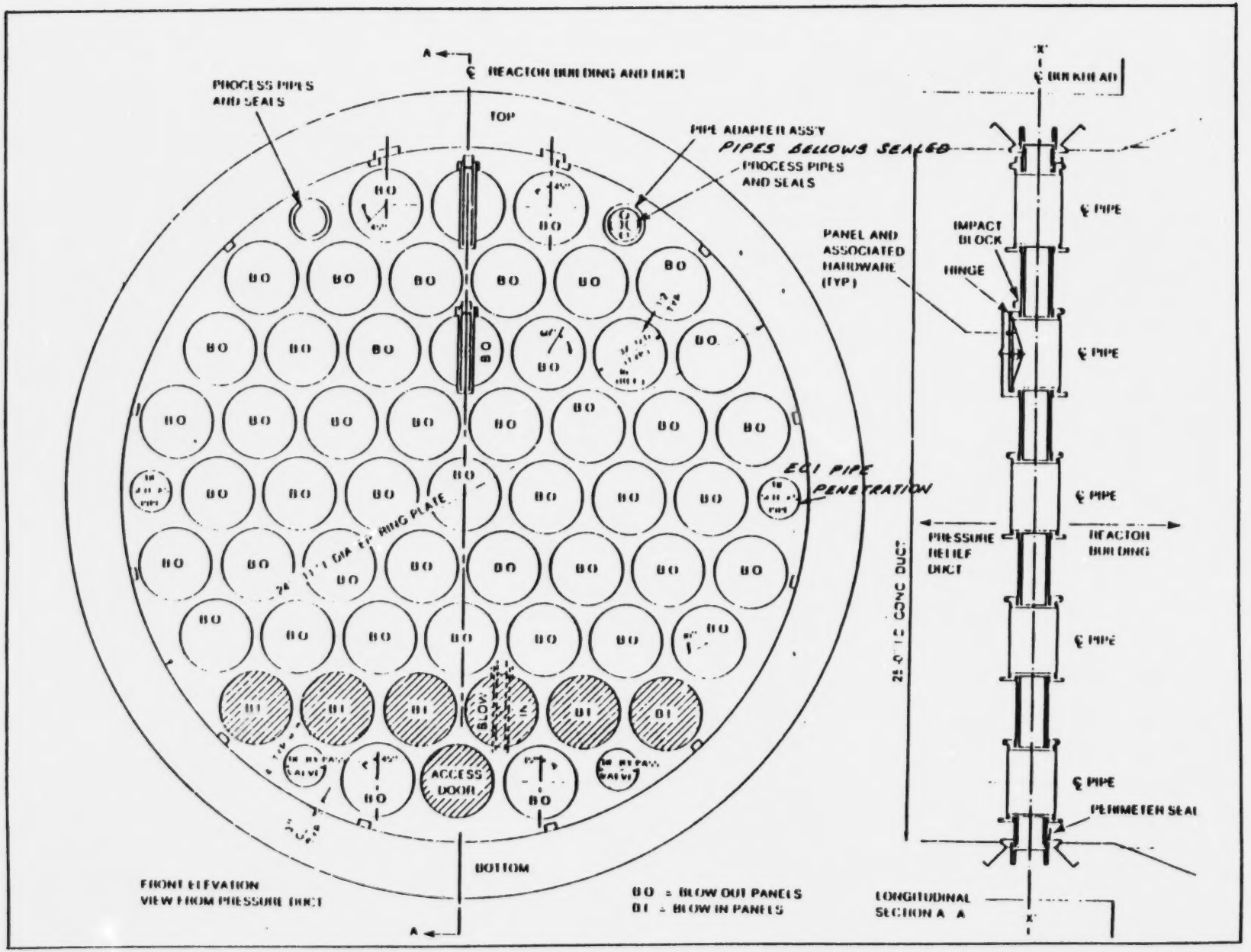


Figure 7: Pickering B Pressure Relief Duct Bulkhead System,Component Location Diagram
(Ref.AECL Technical Specification 30-21101-4)

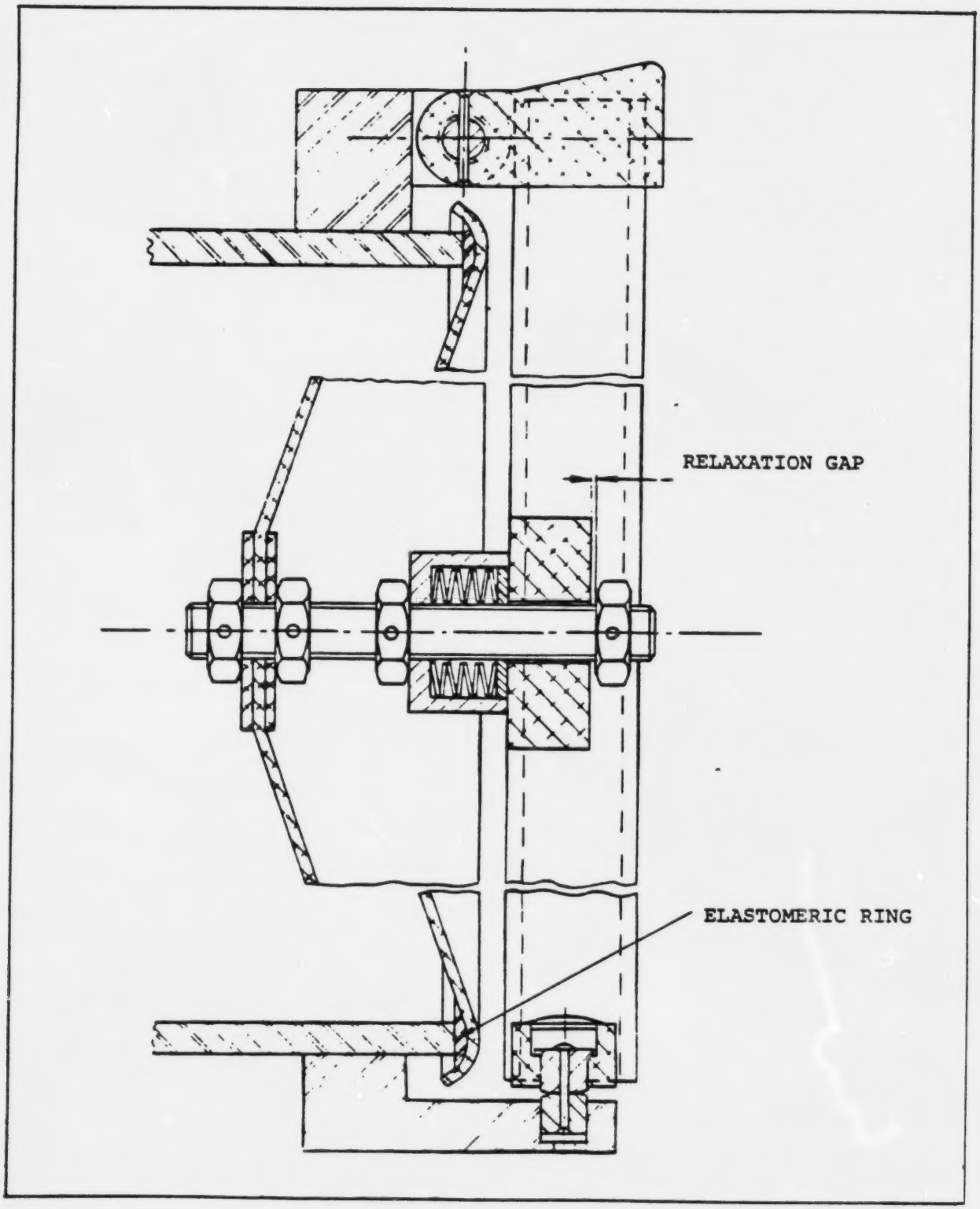


Figure 8: Blow-out and Blow-in Panel Assembly
(Ref.AECL Technical Specification 30-21101-4)

small company in Burlington). The seals around the blow-out and blow-in panels are still Silicone rubber. [Ref. 54]

The design of the seals on the blow-out, blow-in, drop panel and access door assemblies requires pouring in place of the seal. This requirement limits material selection to silicones and polyurethanes. Of the two, polyurethane has superior mechanical properties. If properly formulated and installed, this material can be expected to fulfill the functional requirements for the expected life of the station.

2.3.2 Technical Requirements & Specifications

Dupont lists the properties of their product Adiprene in a specification, but the final properties of the elastomer may vary considerably, depending on what other constituents have been added. Dupont's basic material is tested in accordance with relevant ASTM standards.

CSA Draft Standard N285.3, Requirements for Containment System Components in CANDU Nuclear Power Plants, states that non-metallic materials may be used in flexible bellows and seals which accommodate movements between the containment structure and penetrating system, provided it can be demonstrated that the materials meet the life expectancy requirements for the design conditions. The materials are to be qualified for service conditions and the required service life, taking into consideration both normal plant conditions and accident conditions.

2.3.2.1 Manufacturer Testing

The bellow seals for Pickering B were tested on a test rig at AECL. They were pressure tested, and then a combined axial load and torque were applied, for at least 50,000 cycles. The bellows never failed these tests. When a high internal pressure (above design pressure) was applied, they could slip out from under the clamps holding them in place. Failure of a bellows seal at Pickering B does not result in a breach of containment, but does reduce, acceptably, the trip parameter sensitivity for the safety systems. [Ref. 55]

2.3.3. Operational and Environmental Stressors

Design operating conditions are specified as: [Ref. 56]

Temperature:	$40^{\circ}C$ Normal ($-20^{\circ}C$ to $100^{\circ}C$) ($-4^{\circ}F$ to $212^{\circ}F$)
Humidity:	0-100% Relative Humidity
Radiation:	.01 Gy (1 rad/h) 2.0×10^{3} Gy (0.2×10^{6} rad) cumulative

Seals on blow-out, blow-in, drop panel and access door assemblies are subjected to compression stress. This is the most significant stressor.

2.3.4 Operational Testing

CSA Standard N287.7, In-service Examination and Testing Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants, requires yearly testing/examination of elastomeric parts of containment.

The design specification recommends the following inspection schedule: [Ref. 57]

Blow-out panels: 10% of panels every 2 years,
i.e. 3 panels/year
visual inspection
leak tightness
release pressure set point

Blow-in panels: each panel every 2 years
same tests as blow-out panels

Drop panel: each panel once per year
same tests as blow-out panels

Access Door: once per year
visual inspection leakage

Seals on all of the above must be surface inspected, and must not have any cracks, cuts or tears. Results of all tests must be recorded.

The pressure relief panels are actually tested annually: five blow-out panels and two blow-in per year. [Ref. 58] This inspection is more rigorous than was specified in the design specification.

In addition, the quarterly on-power reactor building pressure tests are capable of detecting leak sizes of 3.2 cm^2 (0.5 in^2), so these tests ensure the integrity of the bulkhead seals.

2.3.5 Operational Experience

Aside from the initial problems at Pickering B with material deterioration and subsequent material substitution, no problems have been reported at Pickering A or B.

2.3.6 Recommended Guidelines for Monitoring Methods and Maintenance

No additional inspection or testing of the pressure relief duct bulkhead components seems necessary, since the intent of CSA N287.7, i.e. yearly inspections/tests is met. These seals do not form a containment boundary, and so are less critical than the expansion joints.

2.4 Pressure Relief Duct Contraction Joints Seals

2.4.1 General

The pressure relief duct at Pickering A and B is not continuous over its supports. At each joint there is an elastomeric contraction joint seal, as shown in Figure 9.

At Pickering A, there are five rectangular joint seals in the pressure relief duct, and four circular joint seals between the pressure relief duct and the reactor buildings. Bruce and Darlington do not have any elastomeric components in the expansion joint, since a metal seal is used.

2.4.1.1 Functional Requirements

The contraction joint seals are required to retain the vacuum within the duct for extended periods of time, and to block the escape of water, water vapour or other gases from the duct, under conditions described in Section 2.4.3. The expected life is 30 years. [Ref. 61]

2.4.1.2 Material

The material is specified as a synthetic rubber, encapsulating a fabric reinforcement. [Ref. 62] For Pickering A, Neoprene rubber was used. For Pickering B the seals are Silicone rubber, with fiberglass reinforcement. [Ref. 57] The supplier was Armet. Neoprene is probably a better choice for this application. The cost is lower and mechanical properties are better. Silicone has better resistance to elevated temperatures, as would occur following a LOCA.

2.4.2 Technical Requirements & Specifications

CSA Standard N287.2, Material Requirements for Concrete Containment Structures applies to expansion and contraction joint sealants. This standard specifies required radiation resistance, ease of decontamination, elasticity and hardness for joint sealants. In addition, physical properties before and after aging are specified. The relevant sections of the CSA Standard are contained in Appendix B.

CSA Standard N287.3, M82 Section 13 on non-metallic liners states that non-metallic liners (and by implication joint sealants) shall be selected with the following criteria in mind:

(1) design service life of components
(2) design accident pressure
(3) temperature and radiation effects
(4) test acceptance of leakage rate
(5) maintainability requirements
(6) type of structure and method of construction.

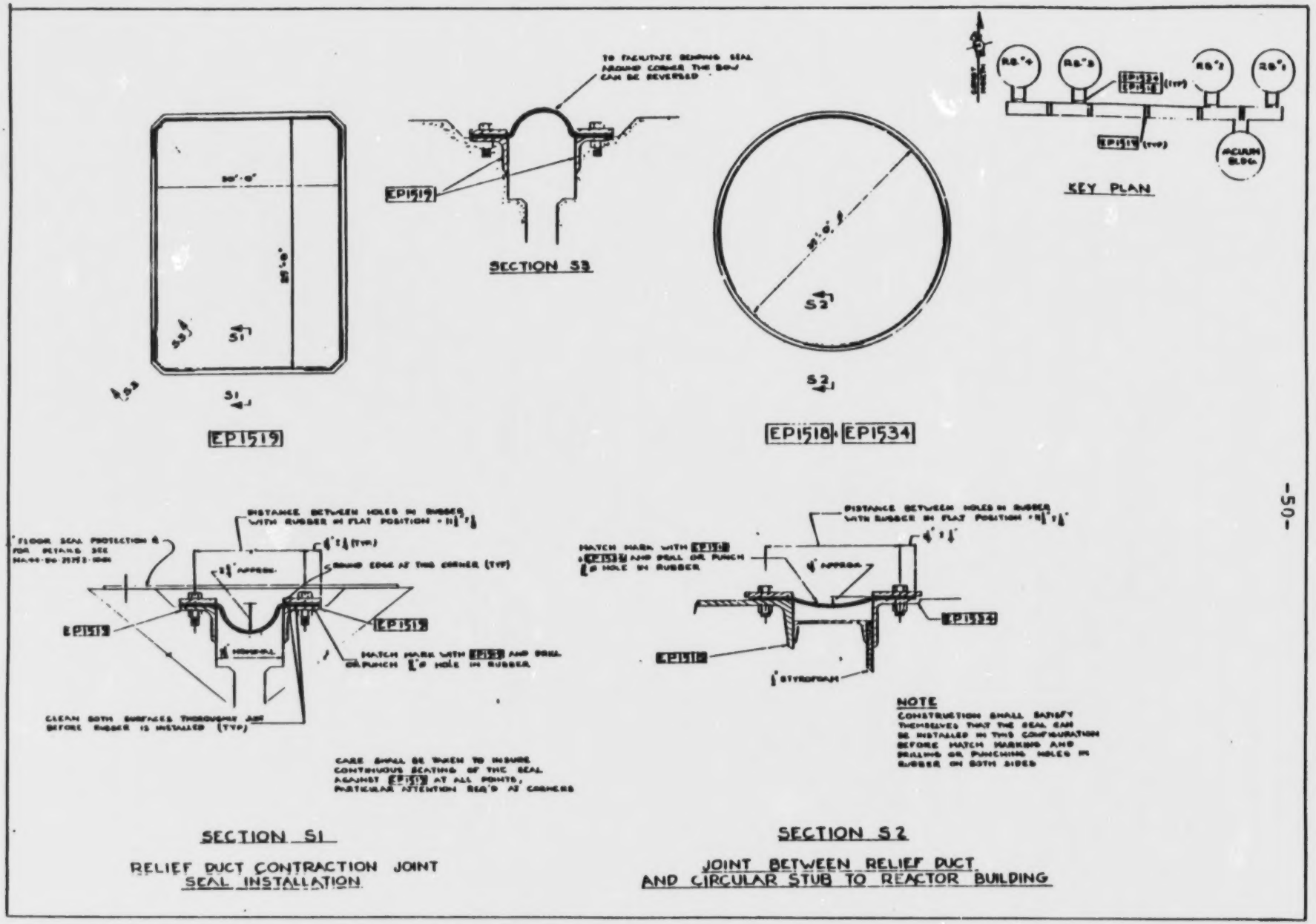


Figure 9: Pickering A Pressure Relief Duct Contraction Joint Seals
(Ref.Ontario Hydro Drawing NA44-DG-25200-1002,R0)

Materials properties of the elastomer specified in Ontario Hydro Procurement Specification include: [Ref. 64]

Main Mechanical Properties
- tensile strength and elongation
- tear resistance
- hardness
- ozone resistance

Stress Relaxation
- compression set
- resistance to pullout (i.e. permanent stretching)

Subsequent to heat aging for 70 hours at 230°C
- hardness
- change in mass
- tensile properties
- retention of sealing backforce

The material specifications in the Ontario Hydro Procurement Specification are not as stringent as the requirements of CSA N287.2.

2.4.2.1 Manufacturer Testing

The Ontario Hydro Procurement Specification requires the manufacturer to provide certified data for the material and testing specified. No post-LOCA or radiation resistance tests are required by the Procurement Specification, although they are required by CSA N287.2.

2.4.3 Operational and Environmental Stressors

The environmental conditions are similar to those experienced by the pressure relief duct airlock seals, and are:

Maximum outside temperature:	32°C (+90°F)
Minimum outside temperature:	-29°C (-20°F)
Maximum temperature inside pressure relief duct:	100°C (+212°F), following a LOCA

Additional stressors are compression stress due to clamping of the seal in place, and tensile and compression stresses due to bending of the seal around corners of the pressure relief duct.

2.4.4 Operational Testing

CSA N287.7, In-service Examination and Testing Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants, requires at least yearly examination/testing of elastomer components of containment system.

The Pickering Design Manual for the Pressure Relief Duct states that the elastomeric seals must be inspected at two year intervals. [Ref. 65] Pickering A operations has indicated that, besides the reactor building pressure test which includes the pressure relief duct, routine inspection is done on the pressure relief duct expansion seals every five years. [Ref. 66]

Since these seals form a containment boundary, it is recommended that a regular visual inspection and hardness check be done, on at least a yearly basis. The intent is to provide some advance warning of imminent seal failure, which might be provided by seal cracking, tearing, or hardening.

2.4.5 Operational Experience

2.4.5.1 Summary of Failure Modes and Causes

The splice in a Unit 5 seal failed during commissioning. It was respliced and retested. During commissioning of Unit 8, the joint seal failed twice at a corner, where the joint seal changes direction. These failures are believed to be caused by improper installation, since there was no evidence of aging or deterioration. [Ref. 67]

2.4.5.2 Frequency of Failure

The two above recorded failures, and a small leak at Pickering A are the only reported incidents, with over 15 years of operation of the Pickering A seals.

2.4.5.3 Methods of Detection

Detection of failure is either provided by pressure instrumentation in the pressure relief duct, or by the reactor building pressure test. Visual examination of the seals is only done about every five years (see Appendix 2.4.3), which is not frequent enough to give any advance warning of impending failure. Durometer hardness of the seals appears to have been measured for the first time in 1987.

2.4.5.4 Maintenance Actions

Repair of the leaks with a sealant, or replacement of seals, as at Pickering B, have been the maintenance actions.

2.4.5.5 Modifications Resulting from Failures

There have not been any deliberate modifications resulting from failures. The replacement seals at the Pickering B units have a different reinforcing fabric, i.e. polyester instead of fiberglass, but this was because of supply difficulties.

2.4.6 Recommended Guidelines for Monitoring Methods and Maintenance

(1) These joints should be inspected on a regular basis for deterioration, i.e. on a yearly basis as required by CSA N287.7.

(2) In addition to yearly visual inspection, yearly hardness measurements of the seals should be made. Increasing hardness will occur with age, and when the hardness is e.g. 20 Durometer points above the original value, the seal should be replaced. Since this requires an eight unit outage, all seals should be replaced at once.

(3) Consideration should be given to replacement of the elastomeric contraction joints with steel expansion joints, such as used at Bruce and Darlington.

3. Airlock Seals

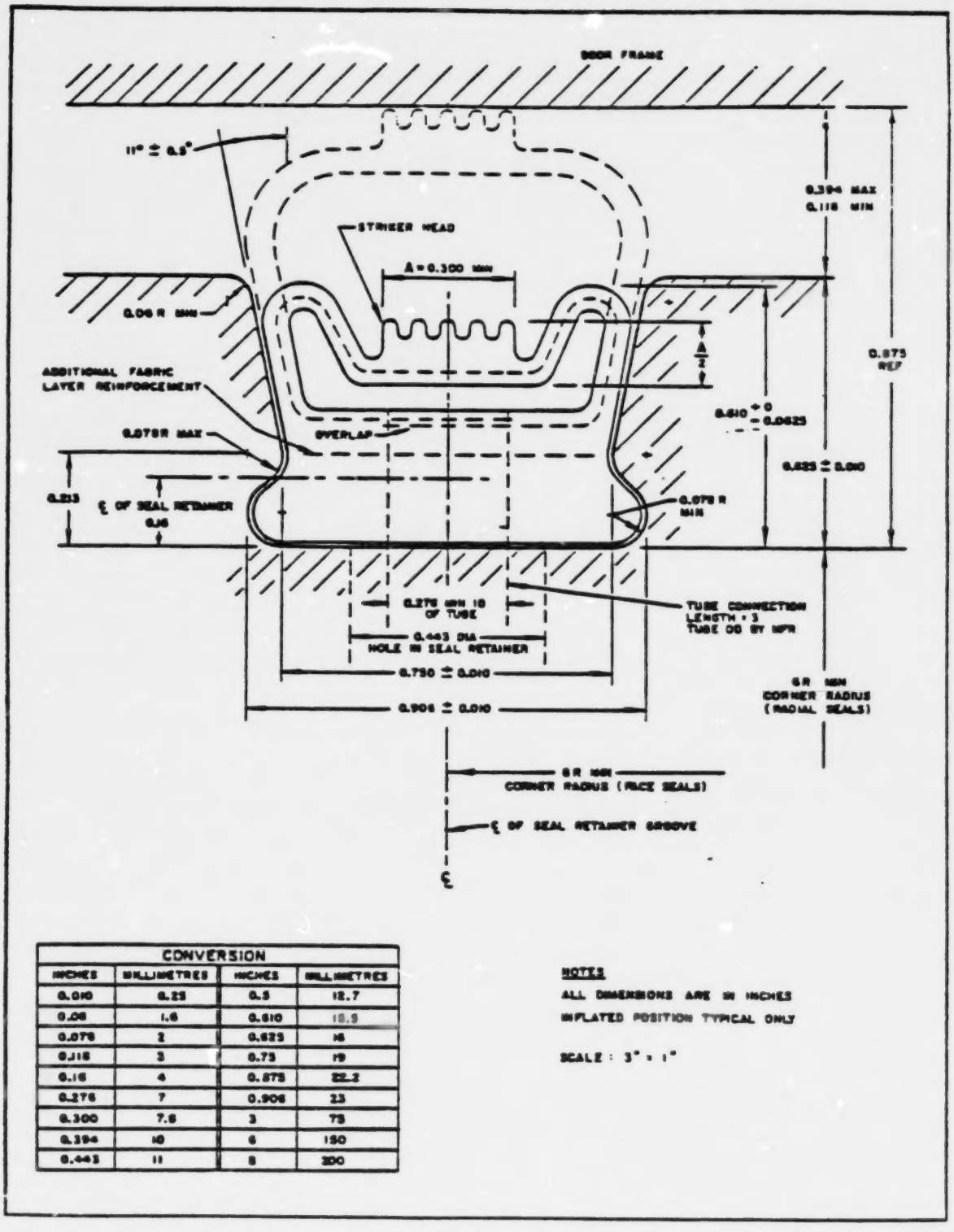
3.1 General

Airlocks provide the means of entrance/exit from reactor buildings and the pressure relief duct without impairing containment of system integrity. An airlock is basically a large metal cylinder, with a door at each end. There are two types of airlocks - equipment and personnel. At Pickering, equipment doors are 2.4 x 2.4 m (8 ft x 8 ft) or 3.0 x 2.4 m (10 ft x 8 ft) and personnel doors within the equipment doors are 1.8 x 0.9 m (6 ft x 3 ft). Doors on personnel airlocks are 2.1 x 1.1 m (7 ft x 3.5 ft). The typical length of an equipment airlock is 7.9 - 8.5 m (26 ft - 28 ft) and 3.0 m (10 ft) for a personnel airlock. Transfer chambers which exist at Bruce, are sets of two doors, in concrete, rather than in the cylindrical steel frame of an airlock.

Airlock seals of two types are in use, viz, "edge" seals and "face" seals. Airlock edge seals are double inflatable rubber seals consisting of tubes, each forming a continuous ring, carried by channels, secured and sealed to the door edge. The tubes run parallel so as to act as backup seals for each other, and seal the door against a framed opening in the bulkhead, to ensure a high degree of leak tightness. All doors have rounded corners, to ensure an adequate seal. Generally speaking, seals may be inflated independently, so that in case of damage to one of the seals, the door can be operated with one seal only. Seal deflation initiation depends upon the design of the airlock, and varies from station to station. Tubes are of the self retracting type and when fully deflated remain clear of the frame and door sill so that no dragging or abrasion occurs. Seals automatically deflate when equipment locks are withdrawn. [Ref. 69] A cross-section of an inflatable edge seal in the seal retainer groove is shown in Figure 10. "Face" seals are located on the periphery of all sliding doors, e.g. on some transfer chambers. The two types of seal are similar in design and function.

At Pickering, there is a second elastomeric seal around the perimeter of the personnel door for LOCA considerations. At Bruce, very infrequently used airlocks and transfer chambers have gasket or O-ring seals, rather than inflatable seals.

For Cernavoda, provision is made for the future connection of a vacuum assisted seal retraction system. This will be installed if the seals, when deflated, stick to the door frames. A pair of flexible seals called perimeter seals are provided for the equipment airlock to compensate for any movement of the reactor building to service building. The seals are installed between the door frame, bolted to the reactor building embedded parts and the barrel of the airlock. These seals allow for differential movements between buildings of up to 2.5 cm in any direction for all



CONVERSION			
INCHES	MILLIMETRES	INCHES	MILLIMETRES
0.010	0.25	0.5	12.7
0.06	1.6	0.610	15.5
0.078	2	0.625	16
0.118	3	0.75	19
0.16	4	0.875	22.2
0.276	7	0.906	23
0.300	7.6	3	75
0.394	10	6	150
0.443	11	8	200

NOTES
ALL DIMENSIONS ARE IN INCHES
INFLATED POSITION TYPICAL ONLY

SCALE : 3" = 1"

Figure 10: Typical Cross-Section of Inflatable Seal in position in Seal Retainer Groove and Frame of Containment Door
(Ref. Ontario Hydro Specification L-625SM-82)

design conditions. This seal is not present at Pickering or Bruce . A pressure tap with plug is provided to the space between the seals for seal testing purposes.

All airlocks meet requirements of Class 2 vessels, Section 3 of ASME, and Pickering airlocks are capable of operation under internal pressures from -41.4 kPag to 41.1 kPag (-6 to to +6 psig), and any pressure from -58.5 to 58.5 kPag (-8.5 to -8.5 psig) occurring in the reactor building or pressure relief duct. Internal airlock test pressure are -58.5 to 51.75 kPag (-8.5 to 7.5 psig). [Ref.51] Pressure ratings vary slightly from station to station, e.g. for Darlington, test pressure for airlocks is 110 kPag (16.1 psig).

At Wolsung, equipment airlocks are 4.3 x 4.0 m (14 ft x 13 ft) for entry of men and equipment, with respectively 3,000 and 100 design operations per year. Personnel airlocks are 0.9 x 2.1 m (3 ft x 7 ft), with 3,000 design operations per year. [Ref. 71]

For Darlington A, the seals are 2.2 cm wide by 1.6 cm high (7/8 in x 5/8 in) when retracted. Seals are designed to seal against the door frame by extending as follows:

Normal extension:	10 mm (3/8 in)
Maximum allowable extension:	13 mm (1/2 in)
Inflation pressure:	276 kPag (40 psig)

Values are different at different stations.

3.1.1 Functional Requirements

The function of the inflatable seals, which are inflated with instrument air, and the perimeter seals, is to prevent gas leakage past airlocks and containment doors. The differential pressure across the seal is normally very low, i.e. a couple of inches of water, but may reach 83 kPag (12 psig) at Bruce stations, and 124 kPag (18 psig) at CANDU 600s during emergency conditions.

3.1.2 Material

The original AECL Technical Specification for the Pickering airlocks specifies that each door will be provided with "inflatable type oxidation resistant rubber or Neoprene seals around its periphery." [Ref. 72] Original airlock seals at Douglas Point and Pickering were of Neoprene, but these were replaced with Silicone rubber, with fabric reinforcement.

On Pickering A and B, equipment airlocks AL1 and AL2 have backup seals to inflatable seals, on the lower half of each personnel door and each equipment door. Seals are designed to prevent gross water leakage from the reactor building through airlocks, in the event of LOCA and ECI (Emergency Core Injection) flooding plus loss of air supply or other

failure of the seals. These seals are compression gasket types of seals, referred to as solid seals. They are fastened to doors with bolted steel retainers, which allow the seals to be replaced. The seals are compressed 1.6 mm to 32 mm against "striker plates." Seals are fabric reinforced phenyl compound Silicone rubber tube with a foam filled core. Solid seals on equipment doors are fabric reinforced phenyl Silicone rubber with a hollow core.

The inflatable seals for Darlington are procured under an Ontario Hydro Purchase Order (OHPO) which includes the requirements of Ontario Hydro Specification L-625SM-82, (Appendix 3.1), but with many exceptions, substitutions and additional requirements.

The inflatable seals for the other OH reactors are procured under OHPOs which are based on the OHPO for the Darlington A seals, but with exceptions, substitutions, and requirements of their own.

Material for the inflatable seals for the CANDU 600 is Silicone based ozone resistant elastomer, with fabric reinforcing. The perimeter seals are flexible elastomeric strips, oil and oxidation resistant and suitable for the temperatures involved.

Silicone elastomers have good resistance to stiffening at low temperatures and adequate radiation resistance, but also have poor mechanical strength and poor resistance to abrasion and tearing.

3.2 Technical Requirements and Specifications

Codes and standards specified in airlock Technical Specification: [Ref. 73]

ASME BPV Code Section III -, "Nuclear Vessels"
Section IX - "Welding Qualifications"
CSA 48.1 - Mild Steel Arc Welding Electrodes
ASTM Part I - Ferrous Metals
CGSB Spec 31-GP-404 Type II
CGSB Spec 1-GP-140b
Canadian Electrical Code CSA Standards

are not applicable to seals per se, but to the airlock structure. Referenced codes and standards are similar for Bruce A and B stations.

CSA Draft Standard N285.3 - Requirements for Containment System Components in CANDU Nuclear Power Plants applies to airlock seals, and were discussed in Section 2.1.2.

Material properties specified for Cernavoda airlock door seals are:

tensile strength
ultimate elongation

tear strength
ultimate elongation after irradiation.

Also after immersion in an acid bath for 30 days:

tensile strength
ultimate elongation
weight change
durometer hardness change

Ontario Hydro Specification L-625-SM-82 specifies the same material properties, but does not require immersion in an acid bath and subsequent testing. Required resistance to radiation is also specified, but not resistance to a LOCA environment.

3.2.1 Manufacturer Testing

Ontario Hydro Specification L-625-82, Inflated Seals for Airlocks and Containment Doors, superceding L-625-71 and L-625-73, calls for the following tests to be done by the manufacturer on random samples of seals:

collapse time
pressure proof test
distortion test
leakage rate test
pressure retention test
fatigue resistance - inflation/deflation
striker head movement

The same tests are required in the airlock seal Specification for Cernavoda. [Ref. 53] No environmental qualification, e.g. post LOCA testing, was specified. Refer to Appendix 3.1 for details of the tests.

In the airlock seal specification, Ontario Hydro requires the seal manufacturer to do the following tests on all seals shipped:

structural integrity (leakage)
pressure retention
collapse time

The following tests are also to be done on a sampling basis:

fatigue resistance
leakage rate across seals
test for distortion and striker head movement

Refer to Appendix 3.1 for details of the testing requirements.

In actual fact, Sealmaster, the manufacturer, does a limited number of production tests:

visual inspection
overpressure test
leakage rate across seals on all seals, and
one seal per production run is tested for 1000 cycles of inflation/deflation

Suppliers of airlock seals vary from station to station. Pickering A, for example, has three types of seals. The original seals were of black Neoprene rubber, and were supplied by Kurkhill. Some of these seals in service are several years old. The second supplier is Haskon, who supplies an orange Silicone rubber seal, with four ridges on the striker head. These are not considered to be of as good a quality as those supplied by Sealmaster, who provides an orange Silicone rubber seal, with three ridges on the striker head. The newer types are designed better, and collapse more fully. Insufficient collapse of the seal and consequent premature wear is a frequent failure cause of the airlock seals. An observation from Pickering Operations is that the Silicone seals now seem to be more abrasion resistant than formerly. Since 1983 Sealmaster has been the sole airlock seal supplier for Ontario Hydro, and will be until 1988, and also for Gentilly-2 and Pt. Lepreau. The seals have been standardized for all Ontario Hydro stations, and the intent is to LOCA-qualify these. These seals are replacing other existing seals at all stations, as they become available.

3.3 Operational and Environmental Stressors

Ontario Hydro Airlock Seal Specification L-625SM-82 specifies that the airlock seals are exposed to the following environmental conditions:

Radiation normally:	10 rad/h, or 3 Mrad/30 year
Neutron dose rate:	2 R/h
Normal max. temp:	71°C (160°F)
LOCA: extra radiation	15 Mrad
temperature:	115°C (240°F) for 2 mins.
	100°C (212°F) for 6 hours
	linear decline to 70°C (160°F) at 12 hours
Humidity:	100% for all conditions

Exposure to radiation at Pickering, is much lower than specified fields are in the range of 10 mrad/hour. Fields for airlock seals at Bruce vary from 0 to about 5 rad/hour on the containment side.

Cernavoda airlock seal specifications state that the pressure drop across seal face is a maximum of 124 kPag (18

psig), and seals will be exposed to:

ozone (1.0 ppm possible)
oil from spillage
light and heavy water
scuffing
weak acids, from action of oxides of nitrogen on water
alkaline solutions, pH up to 10
radiation - 1×10^6 rad over 15 years

By comparison, the airlock specification for the standard 600 MWs specifies radiation fields of 10^4 rad over 16-1/2 years, i.e. an average of 70 mrad/hour.

A very significant stressor is the number of operating cycles, resulting in fatigue and abrasion, when the seal is not fully deflated. For Pickering A and B the estimated number of cycles is: [Ref. 75]

Airlock 1 and 2: 12,000 cycles/year
Airlock 3 and 4: 9,000 cycles/year
Airlock 5 and 6: 1,500 cycles/year

At Bruce A and B, a redesign of the containment system results in much less frequent usage of the airlocks. Airlock 2 is the most frequently used.

Airlock 2:	2,000 cycles/year	Units 1-4
Airlock 5:	500 cycles/year	Units 1-4
TC1-4:	400 cycles/year	Unit 0
Airlock 20:	100 cycles/year	Unit 0

All other airlocks and transfer chambers have less than 100 cycles per year. Darlington usage rates are expected to be very similar to those at Bruce. [Ref. 76]

3.4 Operational Testing

CSA Standard N287.7, In-service Examination and Testing Requirements for Concrete Containment Structures for CANDU Nuclear Plants, requires containment structures to be visually examined and tested where applicable. All organic parts of containment are required to be examined and/or tested a minimum of once a year.

Draft Standard CSA N285.3 also applies, and its implications are in Section 2.1.2.

Pickering A

Pickering Operating Manual 0-21130 specifies that the following tests are to be done annually for the airlocks:

Functional Test
Inflatable Seal Leakage Test
Check Valve Leakage Test
Pneumatic System Leakage Test
Vessel Leak Test

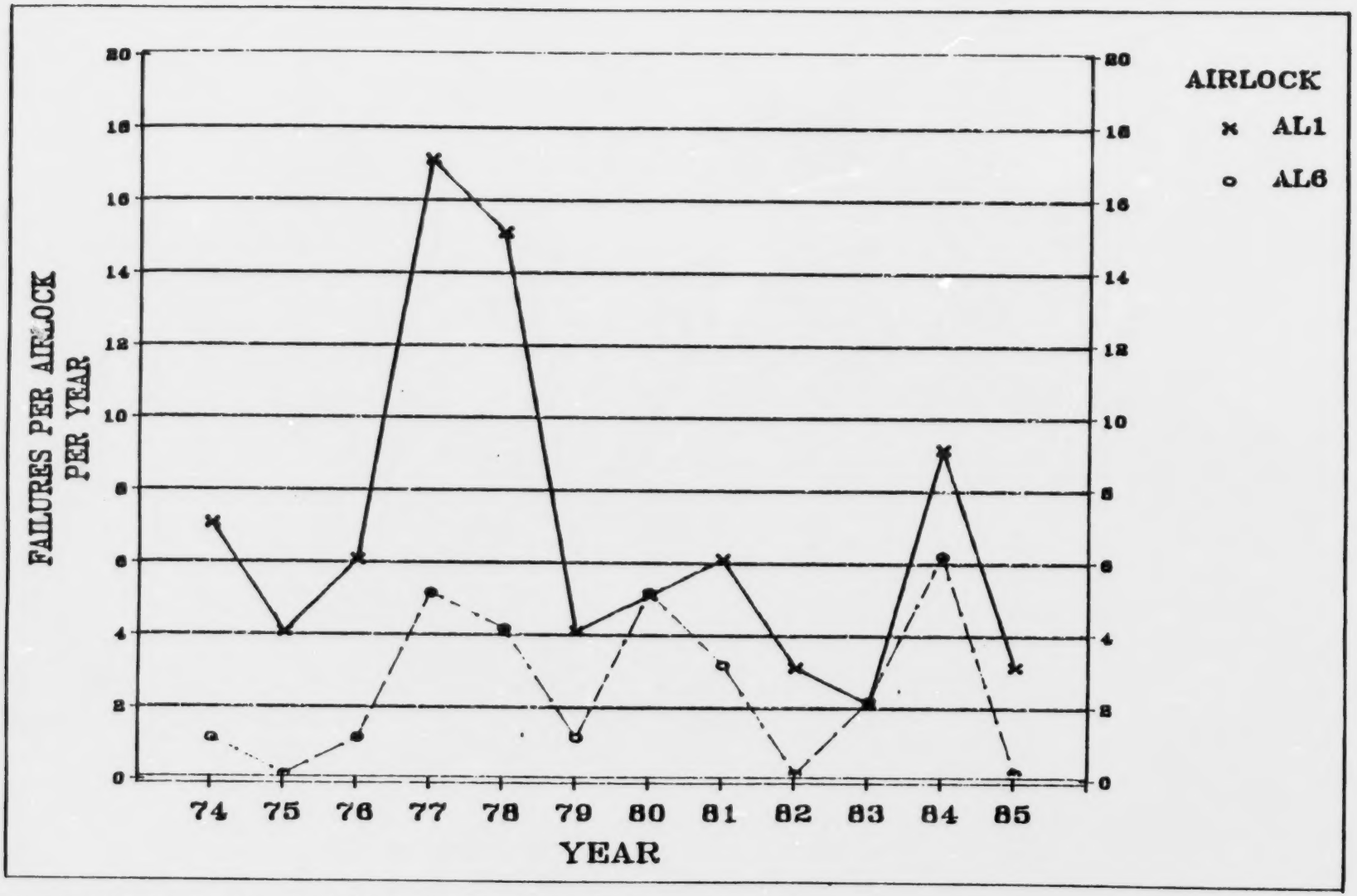


Figure 11: Pickering A Airlock Seal Failure Rates
(All data from Pickering A Quarterly Technical Reports)

For Pickering A, the following tests are scheduled to be done on a routine basis:

Test C-7 - Testing of airlock AL1 and AL2 solid seals. [Ref. 77] This test is done quarterly, and involves filling the interspace between solid and inflatable seals with water and observing leakage rate. If excessive leakage is found, a deficiency report (DR) is to be raised.

Test C-8 - Airlock Inspection. [Ref. 78] Each airlock is inspected every shift, to ensure that containment is not broken. This inspection includes a check on the air pressure gauge for each seal, and a visual inspection of the seals. In practice, seals are not replaced unless they cannot maintain pressure.

Also, at Pickering A, test C13 is performed three times per year to check alarm circuits, and test C14 is performed yearly to test the relief valves.

Pickering A does not have the capability of doing an interseal leak test, as Pt. Lepreau does. An airlock pressure test is done, and if necessary a bubble test is done to see which seal leaks.

Refer to Appendix 3.2 for testing records.

Pickering B

Operating Manual 0-21130 calls up the following tests:

Test C11 - Airlock alarm circuits, frequency three times a year
Test C12 - Airlock pressure relief valve test and pressure test of the airlock shell, once a year
Test C20 - Test for solid seals on AL1 and AL2, quarterly.
Test C21 - Airlock inspection once/shift

The current operational practice at Pickering is to repair any seal leakage as soon as possible, to validate the leak rate of 2% per hour at 42.7 kPag, as claimed in the Safety Report Analysis. If a leak in one seal is greater than the seal supply rate, the pressure in both seals will drop, and an airlock "trouble" annunciation will occur. There are now three different CRT annunciations in the control room for each airlock:

(1) Containment loss
(2) Airlock differential pressure high (DP >1.7 kPad across either door)
(3) Airlock trouble:

    (a) seal pressure low, <140 kPag
    (b) airlock pressure >48 kPag
    (c) vacuum pressure >90 kPag in vacuum tank
    (d) personnel door open >15 minutes
    (e) equalizing valve on either door open

Local annunciation is also provided:

other door in use (spring sequence of door inhibited)
high DP across door
high pressure in airlock (>48 kPag)

Bruce A

Tests for Bruce A are very similar to those at Bruce B, and are intended to be done with the same frequency.

Bruce B

The design intention is that unavailability from airlocks and transfer chambers is not to exceed 1×10^{-4} y/y. Inflatable seals are to be physically inspected and leak rate tested at yearly intervals, maximum. [Ref. 79] Station procedures require airlock leak rate tests to be performed yearly, as detailed in Test 4.1, 4.2, 4.3 and 4.4. Annunciation monitoring tests are done once in two years as described in tests 4.5, 4.6 and 4.7, seal and check valve tests are done once in six months. (Tests 4.8, 4.9, 4.10 and 4.20).

The following monitoring alarms for the airlocks are provided at Bruce:

- Status of door and seals on the opposite side
- Low seal pressure indication locally and alarm in the control room
- Breach of containment annunciation in the control room as follows:
  - one door open, opposite side door seals deflated
  - both doors open
  - both side doors seals deflated
  - equalizer valve vented to one side and the opposite side door open or seals deflated.

Pt. Lepreau

Pt. Lepreau does monthly inter-seal leakage tests on both personnel and equipment airlock doors (Tests 21601.7 and 21601.8) to detect defective seals. If excessive leakage is found both seals are replaced. The perimeter seal for the equipment airlock is also tested yearly (Test 21601.12). With the Haskon seals, if the seals did not pass the test, the first recourse was to clean them. This appeared to result in successful retests a large fraction of the time. Sealmaster has recommended that airlock seals not be cleaned.

Refer to Appendix 3.2 for airlock seal test performance.

Ontario Hydro places emphasis on detection of failure, once it has occurred. Detection of actual failure occurs promptly, due to full instrumentation and inspection every shift. Pt. Lepreau, on the other hand, has placed more

emphasis on detection of impending failure, with monthly leakage tests of the seals, by pressurizing the inter-seal space. This appears to be the best method of detecting impending failure.

Airlock seals are duplicated on each door, with two doors available as a containment boundary. In view of this seal redundancy during all normal operating scenarios and the fact that the unavailability of an airlock during seal replacement does not normally have any effect on station performance, it is probably not justifiable to retrofit the capability of doing interseal leakage tests on existing stations. However, if maintenance and unavailability of an airlock are ever to be planned events, this type of testing will be required.

Development of the airlock sealing system has taken many in-service years, and the focus now seems to be on the seals themselves. Considerable effort has been expended by Ontario Hydro in its negotiations with Sealmaster, and now that there is only one supplier, with a uniform product supplied for all stations, it will be easier to analyze failure causes. Pickering has undertaken a program to monitor manufacturer, service life, failure mode etc. of airlock seals, and the results of this, if carefully done, would be of considerable value to stations with fewer seals e.g. CANDU 600s, or with fewer operating cycles e.g. Bruce.

3.5 Operational Experience

3.5.1 Summary of Failure Modes and Causes

Analysis by Ontario Hydro has provided the following dominant failure modes for various seals: [Ref. 80]

1960-1972 -	Kurkhill, neoprene material failure mode:	cycle fatigue life cracking compression set due to time and/or temperature
1972-1982 -	Kurkhill, silicone material failure mode:	slicing or fatigue cracking at foot of seal failure after 2000-10,000 cycles
	Haskon, silicone material failure mode:	pinholes (probably manufacturing defect)
1982-	Sealmaster, silicone material failure mode:	physical destruction (esp. at Bruce) caused by weight of door against a seal which was not fully deflated

Tests done by Sealmaster indicate an expected life of 20,000 cycles, with radiation. Tests currently underway at Dobson Labs on Sealmaster seals have reached more than 60,000 cycles without failure. The purpose of this Candev program is to determine the flex-life, the effect of flex fatigue on leakage across and through the seals, and the mode of failure from flexing. The intent is to determine service life, and criteria for a periodic replacement schedule for seals. [Ref. 59] Since this is a Candev program, all members of the CANDU owners group will benefit from this information. Tests in the field under controlled conditions would probably be more representative, i.e. with radiation, careless operation, abrasion, and other causes of wear accounted for. However, tests under controlled laboratory conditions are more accurate and reproducible.

Douglas Point

Original natural rubber seals at Douglas Point deteriorated under radiation and ozone exposure. In situ seals failed within six months of installation. A change of material to Silicone was made in 1972.

Fuelling machine vault door seals were inspected in 1983. Some of these dated from 1972, but most from 1979. The material was Silicone rubber, Kurkhill compound 950-C-2142, reinforced with Dacron.

It was concluded that Silicone material was very appropriate for vault conditions, but that there were some non-material related installation problems. [Ref. 82]

Pickering A

Problems were experienced with the original Neoprene seals, especially on airlocks 5 and 6, the boiler room airlocks, and the pressure relief duct airlock. The Neoprene became brittle at low ambient temperatures, which prevented the seals from deflating fully. This prevented door opening or closure. Heaters were installed at these airlocks in 1973, and the seals were largely replaced with low temperature resistant Silicone seals.

Bruce A

At Bruce A there was little difference found between failure rates on service side and containment side doors, indicating that radiation is not a large contributing factor to failure. A 60/40% split was found between inner and outer seal positions and service and containment doors. [Ref. 83]

There are 188 seals in the Bruce A station. The lower usage compared to Pickering is probably the largest single cause of the lower failure rate, i.e. 19 versus 35 replaced seals

per year but because there are so many variables involved, i.e:

- different seal manufacturers, with different manufacturing procedures, materials, etc.
- different operating conditions - temperature, radiation
- different door sizes
- differences in training of personnel using and maintaining seals

the effect of usage alone is impossible to isolate.

Bruce B

Seal deflation times which took too long caused a significant amount of failures, since the door opened before the seals were fully deflated. The resulting abrasion of the seals was the largest contributor to failure. This has been corrected, by adjusting the timer on the door opening.

Pt. Lepreau

As the unavailability and failure rate data in Appendix 3.2 shows, Pt. Lepreau have had difficulties with their Haskon seals. Some of these seals were found to have been in storage for 4 to 5 years before use, and these failed after less than one year of service. Experience so far with the Sealmaster seals, after about one year, has been very good. There have been three occasions where the inflation tube was pulled out of the seal during handling, and two occasions where suspected contact with a solvent caused some of the seal to dissolve. [Ref. 84]

3.5.2 Frequency of Failure

Pickering A

Figure 11 shows the number of seal failures reported in the Quarterly Technical Reports (QTRs) for Pickering A airlocks 1 and 6. Airlock 1 (AL1) is used much more frequently than airlock 6 (AL6), and this is reflected in the higher failure rates. Usage of Airlock 2 (AL2) is similar to that of Airlock 1 (AL1).

Frequency of passage through airlocks is typically 20 to 30 times per day for AL1 and AL2, and 4 times per day average for airlock 6 throughout the year. Causes of failure are not recorded in the Quarterly Technical Reports. The large number of failures in 1977 and 1978 is probably due to aging of Kurkhill seals, about four years after installation. Based on this data, it appears that there may be a five-year cycle of increased failure. This can be avoided by periodic replacement of seals.

A target unavailability of 5×10^{-6} y/y per airlock has been established for all Ontario Hydro stations. [Ref. 85] Pickering A analytical airlock unavailability, arrived at by fault tree analysis, is 7.3×10^{-7} y/y. Deflated seals account for an average of only 3% of the airlock unavailability, while airlock overpressure relief devices and equalizing valves account for 77% and 20% of the unavailability respectively.

The low actual unavailability of the airlocks, as reported in the Quarterly Technical Reports, and recorded in Appendix 3.3 does not indicate the high seal replacement rate, i.e. an average of 35 replacements per year for Pickering A from 1974-1985. There are 152 seals total on all Pickering A airlocks. The replacement frequency varies from seal to seal depending on amount of use.

Sealmaster seals are expected to behave better than the Haskon and Kurkhill seals that they are replacing.

Pickering maintenance stated that so far they have not observed any significant difference in failure rate between the Haskon and Sealmaster seals.

Pickering B

The analytical unavailability, derived by fault tree analysis of the airlocks is the lowest of all Ontario Hydro stations, i.e. 2.8×10^{-7} y/y, compared to a target of 5×10^{-6} y/y. [Ref. 86] Inspection frequency is the same, as at Pickering A, and seal design is the same, but Pickering B has vacuum assist on the seals, which ensures that the seals deflate fully before opening or closing of the door. There were 66 seal failures reported in the Quarterly Technical Reports for 1984, for units 5, 6 and 7. This is very early in the station's life, when airlock use has not yet stabilized. Failure rates should reduce to less than that at Pickering A.

Bruce A

Analytical airlock unavailability, derived by fault free analysis in 1982 for Bruce A is the highest of all Ontario Hydro stations, i.e. 8.68×10^{-4} y/y. [Ref. 87] An in-service report stated that about 180 seals were replaced between 1976 and 1984, 88 of these in 1982 and 1983. The average seal replacement rate over the period 1976-1984 is 19 seals per year. [Ref. 88]

Bruce B

The analytical airlock unavailability for Bruce B was 2.96×10^{-5} y/y in 1982. [Ref. 89] In 1985, the only year for which complete information is available, there were 42 repairs/replacements reported in the Quarterly Technical Reports, of which 19 were in the first quarter.

3.5.3 Method of Detection

Detection of actual failure is either visual, i.e. noticed by an operator during routine use of the airlock or during an inspection, or provided by the airlock instrumentation in the Control Room.

3.5.4 Maintenance Actions

Pickering sends out some of the airlock seals for repairs. Ontario Hydro pressure tests, and does some cycling tests on repaired seals. Generally, repaired seals are more likely to leak than non-repaired seals.

Repair and replacement of seals is generally done within a few hours of detection.

At Bruce, an in-service report states that about 25% of the seals which had been removed (replaced) were found to be in working condition. [Ref. 90] They had been automatically replaced when airlock malfunctions were detected.

3.5.5 Modifications Resulting from Failures

Airlocks at Pickering have had large unavailabilities in the 1970s, as shown in Appendix 3.3. Modifications were made successfully to improve this situation. The major problem that resulted in frequent breaches of containment was the failure of the airlock door seals to inflate, due to leaks and other mechanical component malfunctions and the time to detect this condition. Since 1977, an alarm annunciates in the Control Room, and a light flashes at the airlock, if a seal deflates at any time other than during normal operation. The airlocks were also modified such that the condition for one door seal to deflate is that the other door seal is fully inflated.

Pickering A and B have had a seal failure monitoring program in place for about a year. Each seal failure is reported with the manufacture date, seal location, damage details and cause of failure. This data has not been analyzed yet.

Bruce B

It was reported in 1984 that numerous problems were experienced with leaking air seals. The design caused the seals to vent slowly and incompletely, and the door closed or opened before the seal was fully deflated. Modifications to the design were completed early in 1985. The repair/replacement rate dropped significantly, to an average of nine over the following five quarters, from 19 repairs/replacements in the first quarter of 1985.

3.6 Recommended Guidelines for Monitoring Methods and Maintenance

(1) Monitoring frequency of airlock seals should be related to frequency of use, so daily inspections at Pt. Lepreau are suggested.

(2) Inspections and tests at Bruce A particularly do not have a good record, and this should be improved.

(3) Ensure that seals are not kept in storage for long periods, since they do deteriorate with time, as Pt. Lepreau experience has shown. A "first in, first out," (FIFO) inventory control method is recommended.

(4) An organized ordering system between utilities using these seals (Ontario Hydro, New Brunswick Electric Power Commission and Hydro Quebec) would be very useful. This move should be considered as soon as possible, and implemented if found to be administratively desirable.

(5) Specific guidelines for replacement of seals should be formulated, so that replacement is not only done when the seal will no longer retain pressure. The seal testing program that is presently underway at Ontario Hydro should provide the information necessary to establish an optimum replacement schedule.

4. Fuelling Machine Hoses

4.1 General

A feature of the CANDU reactor is on-power refuelling. During fuelling, fresh fuel is transferred from one fuelling machine to the reactor at one end, and spent fuel is transferred to the second fuelling machine at the other end. The hoses on the machines carry either hot pressurized D_2O (heavy water) or hydraulic oil. There are no hydraulic systems on the fuelling machines at Bruce or Darlington, so no oil hoses are required.

4.1.1 Functional Requirements

The hose assemblies are used to carry heavy water and hydraulic oil (the latter at Pickering and the CANDU 600s only) to and from the fuelling machine, while providing flexibility for fuelling machine motion under the operating conditions described in Section 4.3.

4.1.2 Material

CGE designed and built the fuelling machines and specified the elastomeric fuelling machine hoses for Bruce and Darlington stations, while the fuelling machines and hoses for Douglas Point, Pickering, and the 600 MW stations were designed and specified by AECL. All fuelling machine hoses are manufactured by Aeroquip, and are standard industrial grade hoses.

Hoses at Bruce are used for high temperature and high flow conditions in the magazine supply and return lines, where metal hoses are used on Pickering and CANDU 600's. The design operating temperature has been dropped to about 49°C (120°F) max at Pickering, as part of a program called ambient fuelling, and AECL may use elastomeric hoses on these applications for future stations.

Hoses for Bruce A and B were originally supplied with nitrile (Buna N) interior/Neoprene exterior and an internal layer of carbon steel braiding between these two materials. These were replaced with EPR liner/Neoprene jacket hoses. Aeroquip has determined that the EPR liner/Neoprene jacket hoses can also be used for hydraulic systems, using a synthetic base hydraulic fluid. A new jacket material called Hypalon is expected to be available at Bruce by mid 1987 for testing.

Material selection has been critical at Bruce, where operating conditions are more stringent than at Pickering. Temperature resistance, resistance to oxidative aging and oil resistance are the major properties which have to be optimized. The new jacket material for Bruce, i.e. Hypalon, is expected to optimize these properties.

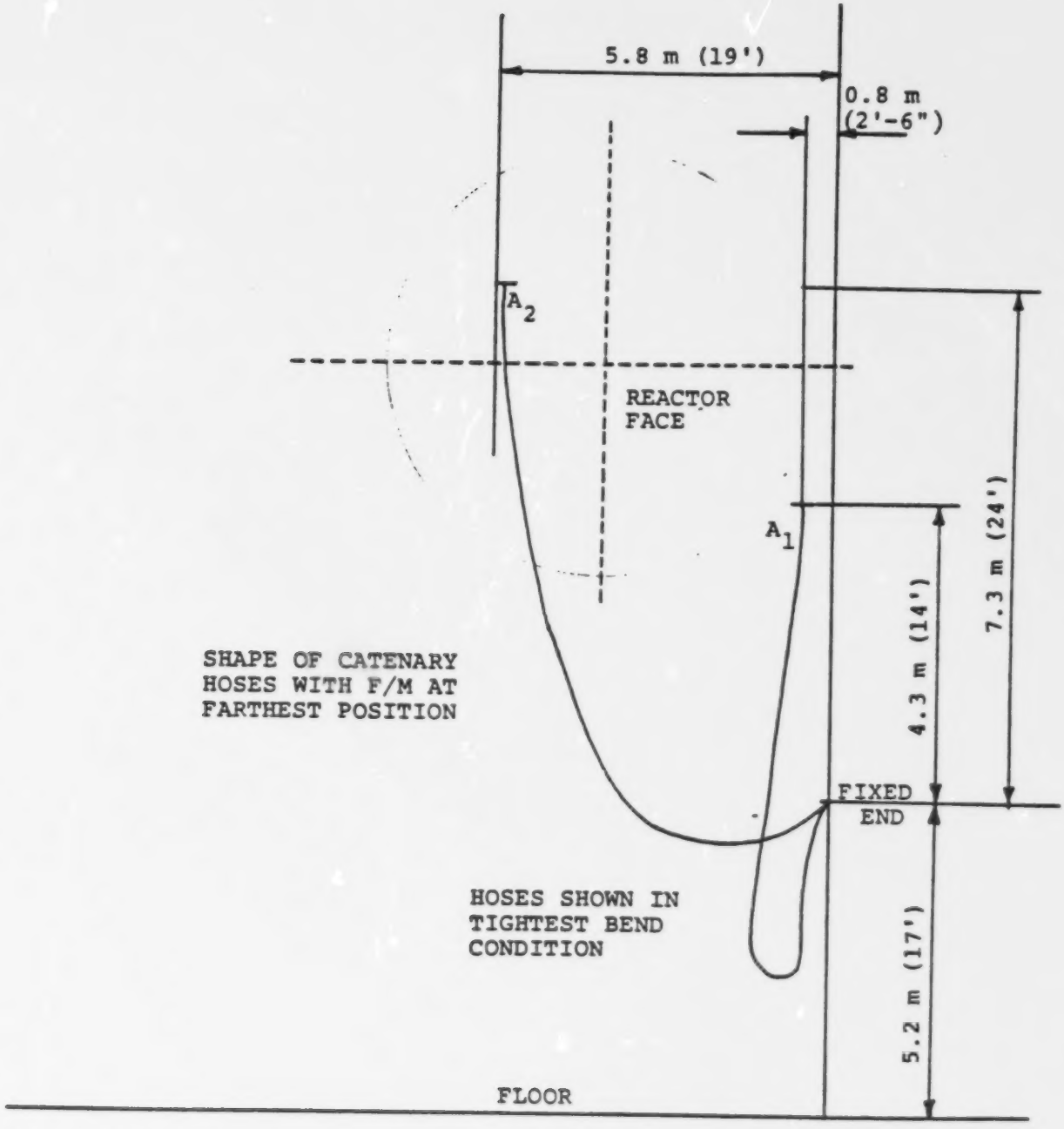


Figure 12: Pickering B Fuelling Machine Hose Installation Geometry
(Ref. AECL Component Specification, SCN 405N0824)

AECL designed catenary system hoses are Buna N interior, covered by a layer of carbon steel braiding or spiral wound reinforcement and an outer layer of Neoprene. The reinforcement is of a design which minimizes changes in length due to internal pressure variations. No material or design changes have been made to the hoses specified by AECL.

A schematic of fuelling machine catenary hoses installation geometry at Pickering B is shown in Figure 12.

4.2 Technical Requirements and Specifications

The applicable standards for hose testing are:

SAE J343	Leak Testing for SAE 100R Series
SAE J517	Hydraulic hose
ASTM D380	
ASTM D573	
ASTM D865	

For a listing of ASTM Standards, Refer to Appendix A.

The following standards also apply:

CSA Z299.3 Quality Assurance Requirements

Proposed CSA standard N285.2, Requirements for Class 1C, 2C and 3C Pressure Retaining Components and Supports in CANDUs (Draft Oct 1986) has not been issued yet, but many of the requirements in this proposed standard have been met for existing stations.

CSA N285.2 states that elastomer hoses may be used in Class 2 and 3 systems, but only where the system function can not be readily achieved using other methods, and if a failure does not cause the accident dose criteria for the general public or operating personnel to be exceeded. The hose shall be reinforced with either fabric or metal reinforcement, and the draft standard states that the design specification shall stipulate where additional tests are required to show resistance to oil, ozone, radiation, vacuum or any other substance which may have a detrimental effect on the life of the hose.

The Draft Standard covers design, materials, fabrication and hose replacement, and once it is in force, will provide thorough guidelines for operations.

4.2.1 Manufacturer Testing

The AECL technical specification for the fuelling machine hoses states that there is no traceability of materials required for non-metallic pressure retaining components. [Ref. 92] A manufacturer's certificate of compliance is required, certifying that all materials are as stated in the drawing.

The above mentioned specification states that the design should ensure that failure is not sudden, e.g. bursting of hose or separation of end fitting from hose, but gradual; such as due to increasing leakage. The specification also states that it is the responsibility of the supplier to register the hose assemblies for use as Class 2 or 3 pressure retaining components, but this has been the cause of quite some controversy, since ASME does not define hoses as nuclear grade components.

The Test Requirements for Pickering Fuelling Machine Hoses are:

Hydrostatic testing: 1.5 times the design pressure, i.e. 4500 psig, held for 15 minutes.
Burst test: 9000 psig minimum, at room temperature

Pressure cycles from 0 psig to 2000 psig to 0 psig, minimum 4000 cycles without leakage.

There are no listed requirements for resistance to oils or ozone, probably because the high pressures and radiation fields are the limiting environmental stressors. For Bruce, similar manufacturer hose testing is specified, and done.

Proposed standard CSA N285.2 states that the following tests shall be done to qualify the fabrication of each hose assembly or bulk hose:

(1) Burst testing at four times design pressure

(2) Leak testing in accordance with SAE J343

(3) Proof testing to 2-3 times design pressure

(4) Impulse testing in accordance with SAE J343, for a minimum of 100,000 cycles

(5) Visual inspection

(6) Dimensional check

(7) Whatever additional tests specification requires

These requirements are somewhat more stringent than those specified for Pickering B, which are listed above.

LOCA qualification of the hoses is not considered necessary. A hose rupture will not result in a LOCA, because flow fuses, which close when there is a sudden drop in line pressure, prevent this.

Aeroquip 2781 Hi Impulse SAE100R2A hoses are used as fuelling machine hoses for the CANDU 600's, NPD, and Pickering , and were used at Bruce and Douglas Point.

4.3 Operational and Environmental Stressors

Operating conditions are: [Ref. 93]

Ambient Temp:	21-49°C (70-120 °F)
Humidity:	95%
Ozone & nitrous oxide:	Trace amoupts
Radiation:	up to $2x10^5$ Gy ($2x10^7$rad) per year, gamma and neutron
Design Pressure:	20.7 MPag (3000 psig)

Environmental conditions specified for the standard CANDU 600 design are only slightly different: [Ref. 94]

Ambient Temp:	19-49°C (65-120 °F)
Humidity:	95%
Ozone & nitrous oxide:	Trace amounts
Radiation:	$3.65x10^4$Gy ($3.65x10^6$rad)/y gamma
Design Pressure:	18.6 MPag (2700 psig)

Environmental conditions specified in the CGE specification for Bruce A fuelling machine hoses are very similar, although the humidity is 10-50%.

The following D_2O flow operating conditions are from a Pickering B design specification and from an Ontario Hydro report: [Refs. 95 and 96]

Fluid type:		D_2O with pH controlled between 9.8 & 10.5 by addition of LiOH or NH_4OH
(1) Pressure cycle:		0.9 to 3.45 to 10.3 MPa(g) (130 to 500 to 1150 psig)
(2) Pressure rate change:		4.61 MPa/s (600 psid/s)
(3) Fluid working temperature cycle:		27-55°C (80 to 130°F) 38°C normally 380 cycles/year
(4) Pressure Cycles Super-imposed on Basis Pressure Cycle in (1) above:		
(5) Duty Cycle (Average) -		3.5 cycles of (1) above per day for 250 days/year
(6) Unusual Operating Conditions	(i) -	Fluid pressure 16.5 MPa(g) (2400 psig) Fluid temp: 55°C (130°F) Duration of condition: 30 min Estimated occurrences: 10 times in 30 years

and	(ii) -	Fluid pressure 10 MPa(g) (1450 psig) Fluid temp: 293°C (560°F) Duration of condition: 30 min Estimated occurrences: 10 times in 30 years
(7) Shutdown Conditions	-	System is idle at 49°C (80°F) and 0 MPa(g) (psig) for approximately 12 h/d for 250 d/y and 24 h/d for 115 d/y

Actual in vault time is about 800 hours/year (9% of the time). [Ref. 97]

Conditions at Bruce A and B are somewhat different for the D_2O hoses:

Pressure:	0-11.03 Mpa(g) (0-1600 psig)
Temperature:	27-93°C (80-200°F)
Pressure Cycle:	0-11.03-0 Mpa(g) (0-1600 -0 psig) 1250 cycles

as the operating temperature is considerably higher than at Pickering. Actual in vault time is about 7900 hours/year (90% of the time). [Ref. 98]

The main operational stressors at Pickering are high pressures, high radiation fields, and frequent flexing. The effects caused by these stressors are difficult to isolate, since their effects are synergistic: Buna N has excellent resistance to oils and hydrocarbon fuels, good tear and abrasion resistance, but poor ozone resistance. Maximum service temp of the material is 150°C (302°F). Neoprene has good resistance to ozone, oxidation, water, and heat aging. It's maximum service temperature is 107°C (225°F). Bruce normal operating temperature of 70°C, with temperatures up to 93°C (200°F) in unusual circumstances, does not leave a wide safety margin for this material. Neoprene and Buna N have good radiation resistance.

For Pickering and the CANDU 600's, the hose is self-supporting over its entire length in its installed condition. The hose is capable of being bent through 90° over its entire length. The twisting will occur about 3500 times over a period of five years, with the hoses pressurized at 600 psig, and 130°F temperature. The Bruce A and B fuelling machine specifications state that no twisting loads are applied to the hoses. [Ref. 99]

Dissolved oxygen in D_2O at Pickering is low; <4 ug/kg during fuelling, and 5-8 ug/g when idle (90% of the time), because the fuelling D_2O is drawn from the main heat transport system. Dissolved oxygen levels are the same at Bruce. Significant differences between operating conditions at Pickering and Bruce are: operating temperature (higher at Bruce), the amount of time the fuelling machine hoses spend in the vault, the number of cycles/year, and the amount of hose twisting.

4.4 Operational Testing

The hoses for the CANDU 600s and Pickering were intended for a service life of five years i.e. from the day the hoses are removed from storage. [Ref. 100] Practical life is assumed to be three years at Pt. Lepreau. Originally, hoses at Bruce were expected to have a two year life, but a large effort is in place to extend hose life to five years. Hose life at Pickering is phenomenal, in that the original hoses are largely still in use, since the early 1970s.

Pickering does periodic visual checks of fuelling machine hoses, during routine fuelling machine maintenance. Recently, several hoses were taken from the Unit 3 fuelling machine and pressure tested to 3000 psig, which is the design pressure. One hose failed this test, and ruptured, but it was a metallic hose, not a rubber one. A rubber and metal hose replacement program is in progress at Pickering A station.

Bruce A has initiated a detailed QA procedure for the fuelling machine hoses, and this has been duplicated at Bruce B. The fittings are put on the hoses at site, hoses are tagged, and recorded. Every hose is hydrotested at 18.6 MPag (2700 psig) for 20 minutes. [Ref. 101] Every two years, head hoses are replaced, since they are contaminated ($\sim$100 mR/h). Catenary hoses are replaced when the jacket is peeling.

All hoses, i.e. eight head hoses and eight catenary hoses for each trolley, are inspected every three months. Also, D_2O temperature is monitored and if it exceeds 90°C, which occurs very rarely, all head and catenary hoses are automatically replaced.

Pt. Lepreau does a visual check every four weeks, for condition of hoses, scrapes, and embrittlement, and weekly inspections for leaks and drips. Hoses are not pressure tested.

The degree of testing and examination done at the various stations corresponds to the operating experience. Pickering has experienced no problems, and does less testing and examination than Bruce, where conditions of opertion are more severe and failures are not uncommon occurrences.

It is recommended that all stations adopt a routine visual inspection schedule of the hoses, e.g. every 2-3 months. Deterioration of the hose jacket will be evident from visual examination, and should be replaced if it appears that the reinforcing braid is or will be exposed. As the liner hardness increases by about 20 Shore A Durometer with oxidative aging, a running record of liner instantaneous hardness measurements, preferably taken by the same person, would provide a good indication of aging, and when to replace the hose. A non-destructive hardness method is required in order to implement this recommendation. The practicality of pressure testing the fuelling machine hoses on a regular basis, e.g. yearly, should be examined. More sophisticated techniques, such as eddy current testing, could be used to detect irregularities in the reinforcing braid, but this would not provide much advance warning of impending failure. Densitometry and differential scanning calorimetry are present lab techniques, which are not adaptable to the field, since they are destructive tests.

4.5 Operational Experience

4.5.1 Summary of Failure Modes and Causes

Hose life can be considerably reduced by flexing the hose to less than the minimum bend radius, twisting the hose, kinking, rubbing or crushing the hose, and subjecting the hose to high temperature and high pressure surges.

NPD

There were two hose failures prior to 1977, and these hoses had been in service for six to seven years. It was concluded that limiting service life to four to five years would avoid these failures. Hoses failed in November 1977 and January 1978, after 2-1/2 years service. There were also several hose failures at Bruce A, after 1-1/2 years service. AECL and Ontario Hydro both investigated the cause of these early failures, and concluded that the ruptures were caused by embrittlement of the liner, which resulted in liner cracks, followed by the oxygenated D_2O corroding the carbon steel hose reinforcing braid, which provides all hose strength. [Ref. 102 and 103 respectively] Embrittlement of the liner was caused by long storage periods (up to 4-1/2 years), high temperature oxygenated water, 5 ug/g oxygen during idle time (90% of the time) and flexing of the hoses. The latter is a combination of bending, twisting, and possibly pressure cycling. Radiation was discounted as a cause of failure, although the hoses had been exposed to 10^5 to 10^7 rad.

Douglas Point

There was a rupture in March 1975, of a hose which had been in service for seven years. The liner was crazed, the cover

cracked, and the braid rusted. There was another burst fuelling machine hose at Douglas Point in about 1980. Hot water in the magazine return line flashed to steam when the line ruptured. The hose was brittle, and had been in service about 2-3 years, whereas the designers claimed replacement was to have been every year.

Pickering A

Although Pickering has Buna N/Neoprene hoses, operating temperatures are lower than at other stations. (Douglas Point up to 150°C, NPD up to 75°C, Bruce up to 80°C) and dissolved oxygen is low (<10 ug/kg). No hoses have failed, but Pickering A replaced hoses last year as a safety precaution on one of the reactor units. The "Pickering Upgrade Program" for units 1 and 2 includes a scheduled replacement of fuelling machine hoses.

Bruce A

Starting in 1978, Bruce A has had many failures of the nitrile (Buna N)/Neoprene hoses (Aeroquip CR-114-16) with CS reinforcing braid. (Refer to Appendix 4.2 for Extracts from the Quarterly Technical Reports). In 1981, experimental hoses with stainless steel liners were tried. This was not successful as stainless steel has a lower burst strength or impulse resistance than carbon steel, and does not allow as much hose flexibility as the carbon steel reinforced hose. Also, the hose fittings did not clamp onto the hose as well, because of the stainless braid. Testing done by Ontario Hydro Research and Aeroquip, the manufacturer, resulted in the fuelling machine hoses at Bruce being replaced with neoprene exterior, EPR interior, carbon steel braided hoses, Aeroquip CR-166-16. [Refs. 104 and 105]

The changeover was completed in mid 1984. Only one of these hoses has failed, and the failure was attributed to a poor fitting match. This has resulted in a test to determine the appropriateness of re-using fittings. New liners are standing up well, but the Neoprene jackets are cracking and peeling after 18-33 months of service life. Analysis by Ontario Hydro Research found that the cracking was initiated on the inner surfaces and propagated from inside to outside. This is attributed to oxidative aging, as the inner surface of the cover is hotter. [Ref. 106] Radiation is not considered a cause of cracking. The oxidative aging was found using differential scanning calorimetry, which showed that the anti-oxidant had been almost completely used up on the inside surfaces of the cover. Research is now developing a new hose jacket with Aeroquip, made of Hypalon, for combined oxidation/oil resistance. Some oil does drip on the hoses from bridge components.

Bruce B

Bruce B recorded 6 head hose and 15 catenary hose failures in the 3rd Quarter, 1985. All hoses were replaced with tested spares made from Aeroquip CR166 hose, with ethylene propylene liner/ neoprene jacket which is more resistant to hardening caused by in service conditions of heat and flexing through motion. A general replacement program for all Aeroquip CR114 hoses started in late December 1985 and the fuelling machine hose replacement program was completed in mid 1986.

Pt. Lepreau

Pt. Lepreau has reported no problems with fuelling machine hoses themselves, but has experienced problems caused by improper torquing, and less than perfect seals with the fittings. They would like to extend the three year shelf life. Since operating conditions are the same as at Pickering, where hoses last 10 years or more, this appears to be quite safe.

4.5.2 Frequency of Failures

There have been relatively infrequent hose failures at NPD, and Douglas Point, and many failures at Bruce A and B. No failures of hoses have been recorded at Pickering, except during pressure testing after 15 years service, and no failures have occurred on the CANDU 600's. The life of hoses is clearly dependent on external stressors, since the same hoses have an expected life of less than two years at Bruce, and more than 15 years at Pickering.

4.5.3 Methods of Detection

Failure detection of hoses is provided by instrumentation on the hoses themselves and the fuelling machine head. Low pressure alarms on the D_2O circulating system, or high temperature alarms on the fuelling machine head, would indicate a break. Also, moisture detectors called beetles, located on the floor, would alarm when the water from a burst hose landed on the floor. Imminent failure of the hose is sometimes detected by visual inspection and is indicated by cracking, hardness or lack of flexibility of the hose. Hardness measurements are not normally done.

4.5.4 Maintenance Actions

The maintenance crew checks the hoses visually for deterioration, and replaces them when deterioration is evident. At Bruce A and B, a detailed procedure for replacement of hoses exists.

4.5.5 Modifications Resulting from Failures

As a result of early fuelling machine hose failures at NPD and Bruce, a testing program was initiated to investigate alternative hose materials. This testing resulted in the changing of the hose liner from Buna N to EPR. The jacket liner is also being changed, at Bruce A and B only, to Hypalon, since the existing neoprene hose jackets are cracking after little service. Stainless steel reinforcing braid was also tried and found to be less satisfactory than hoses with carbon steel braid. The early hose ruptures at Douglas Point led to the duplication of return hoses on the Pickering fuelling machines, and the addition of motorized valves to remotely isolate the hoses. Flow fuses have been installed at subsequent stations, i.e. Pickering A and B, Bruce A and B. These valves close if there is a sudden drop in pressure, i.e. if the hose bursts.

Bruce is installing flow injection into the fuelling machine D_2O system from the Heat Transport System, which will reduce operating temperatures. This will presumably lengthen fuelling machine hose life considerably. It would be of some benefit to monitor the performance of the old EPR/neoprene hoses under these conditions, to see how large a factor temperature is in the deterioration of the Neoprene cover. It may be that the new hoses are not required.

At Bruce B, storage periods for hoses have been minimized and storage conditions optimized, i.e. hoses are not stored in the coiled position, or with fittings installed. Hoses are stored coiled at Pickering, but this does not appear to have adversely affected service life.

4.6 Recommended Guidelines for Monitoring Methods and Maintenance

(1) Store hoses in a dark area, without fittings at the ends, and in an uncoiled position as far as possible.

(2) Adopt a routine visual inspection schedule of the hoses in use, for example, every 2-3 months. Results should be recorded, and on file.

(3) Take non-destructive hardness measurements of the hose. Increasing hardness is a good indication of hose aging.

(4) Each station has somewhat different operating conditions, so the optimum life of hoses is best determined at the stations. Some consistency of replacement schedules should exist, and be coordinated between utilities, as far as possible.

5. Cable Penetrations

5.1 General

All cables penetrating the containment perimeter walls are arranged in such a manner that the internal atmosphere within the containment structure can not leak out via these penetrations.

For instrumentation cables, a short length of the cable inner and outer jackets is removed at the point where the cable passes through the reactor building wall, and an epoxy resin sealing block is cast around the cable at this location. The epoxy penetrates amongst the insulated conductors filling all the air spaces and, in addition, forms a shoulder around the outside of the cable. The cable passes through the containment wall with the epoxy molded seal fitting inside a gland housing, which is welded into a steel plate located over the wall penetration. A gland nut which screws onto the gland housing seals against the above mentioned epoxy shoulder. [Ref. 108] Refer to Figures 13 and 14.

The sealing arrangement is similar for power cables, except for cables sized larger than 4 #12 AWG conductors. In this case the conductors are stranded and the cable is cut at the point where the Cadweld cable seal block is to be provided and then incorporated into the epoxy cable seal block. [Ref. 109]

The primary gland, which is part of the cable penetration assembly, is an internally stepped steel tube with an arrangement of closure hardware to hold and seal the epoxy encapsulated cable: [Ref. 110]

1 gasket
1 gasket holder
2 spring washers
2 flat washers
1 gland nut

The closing gland nut is turned onto the gland until it bottoms on the gland body. The wave spring washers supply continuous pressure to allow for any relaxation of the rubber gasket.

At the CANDU 600 stations only, a unique design of penetration was developed for high voltage 15 kV cables. The outer insulating layers on the cable are removed, wires are Cadwelded together, and then enclosed in several layers of ethylene propylene rubber tape, Si paint, grounding tape, and epoxy and then a final layer of ethylene propylene rubber. [Ref. 111].

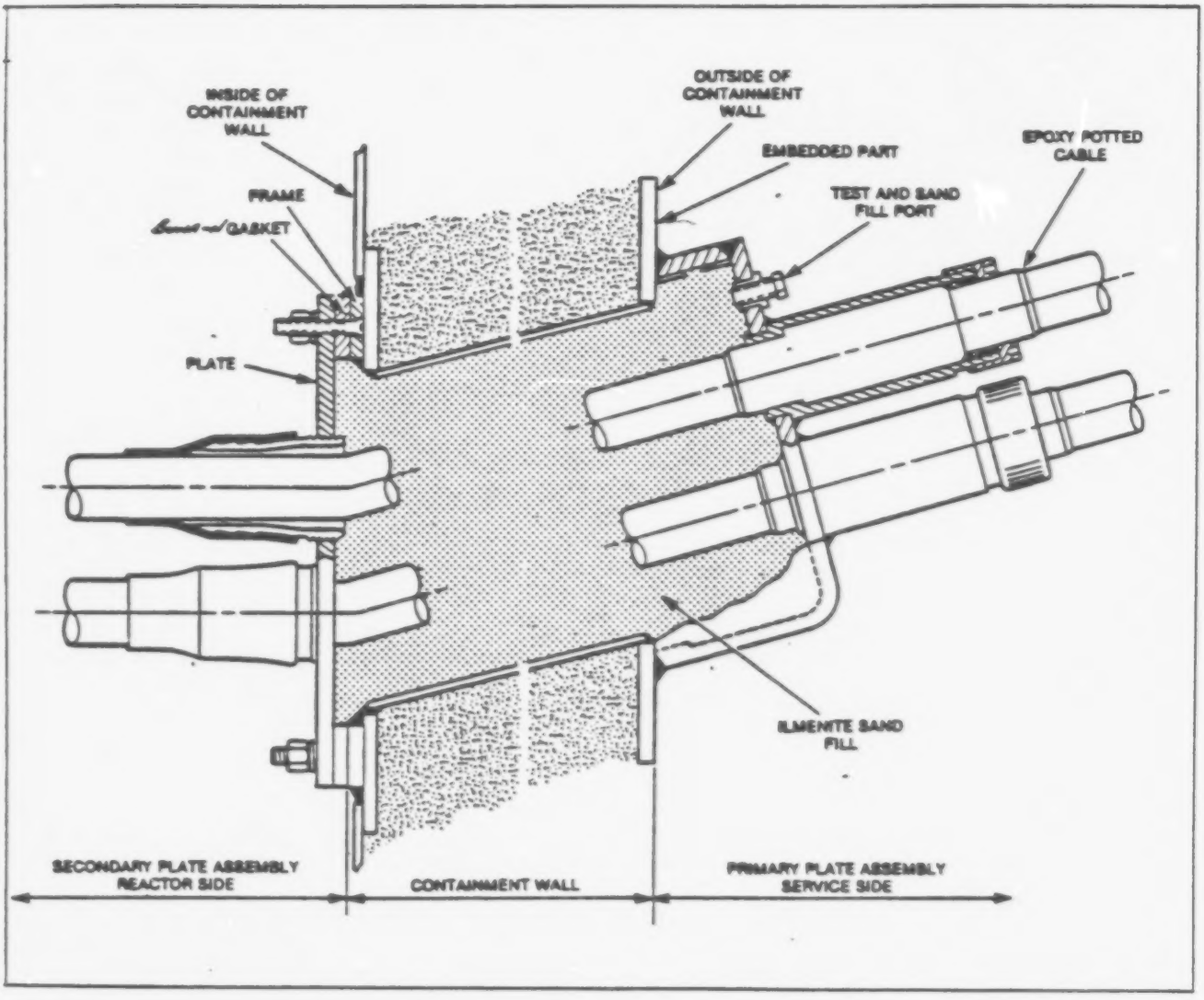


Figure 13: Cable Penetration Assembly
(Ref. AECL Design Manual 29-57600-1)

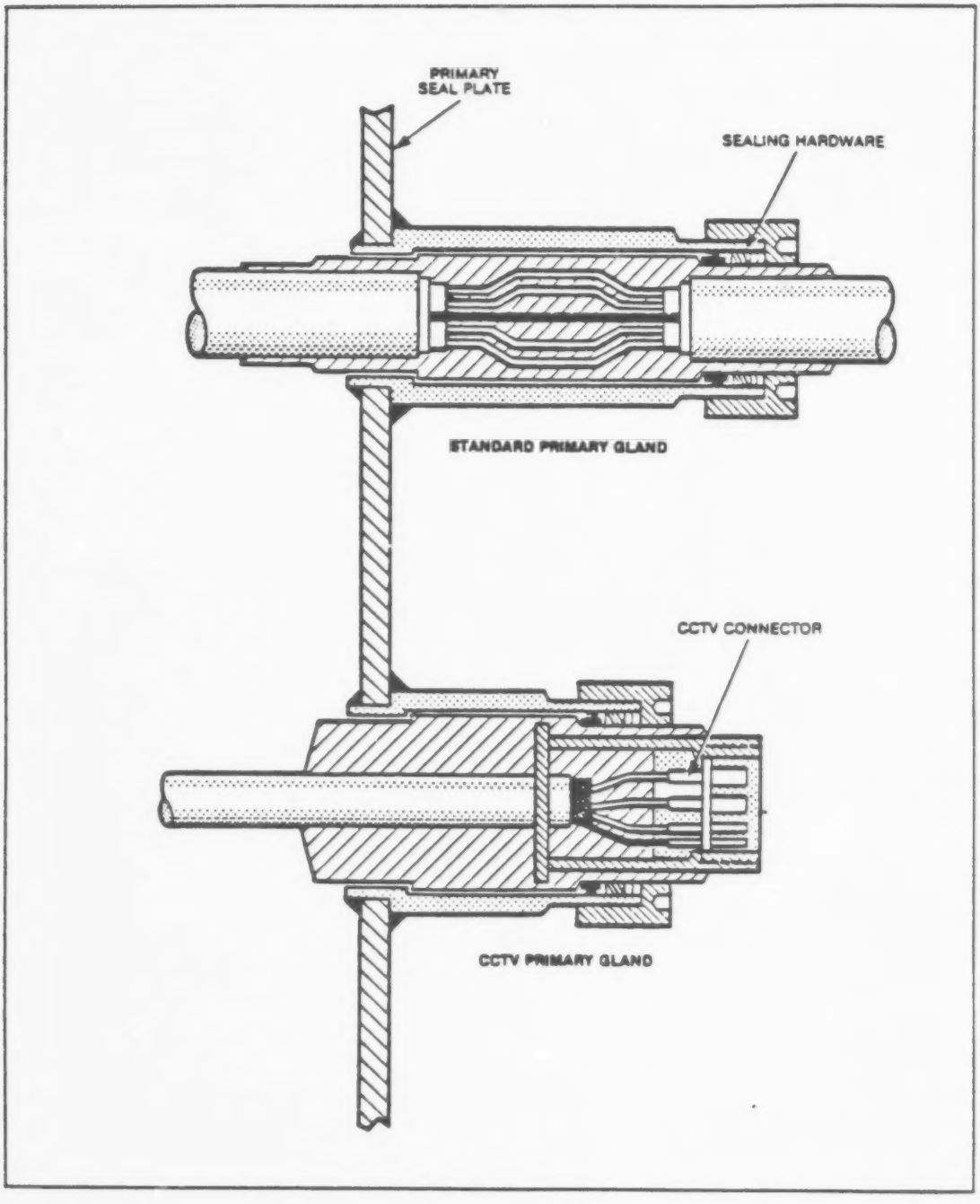


Figure 14: Primary Seal Plate Gland
(Ref. AECL Design Manual 29-57600-1)

At Darlington, cable penetrations are an integral assembly of epoxy, with no elastomeric components. This virtually eliminates all potential sources of leakage, and will probably prove to be a superior design.

5.1.1 Functional Requirements

All cable penetrations are designed to prevent leakage of the atmosphere from inside the reactor building to the outside, and to withstand the environment conditions listed in Section 5.3.

5.1.2 Material

At Bruce, the gasket inside the primary gland is silastic rubber. The gasket on the secondary side is Buna-N. [Ref. 112]. Both materials, i.e. Silastic rubber and Buna N, have excellent retention of properties at high temperature, and are capable of withstanding the expected radiation fields for the 30 or 40 year life of the station.

Material for the gasket on all CANDU 600s is Dow Corning JRTV. This material was chosen for its shear strength, radiation resistance and ease of molding.

The ethylene propylene rubber in the 15 kV penetrations was chosen primarily for its electrical insulation properties, and water resistance. Radiation resistance was not a major concern, since radiation fields are generally <10 mrad/h at cable penetrations, resulting in an integrated lifetime dose of 3.5×10^3 rad. Ethylene propylene rubber has good radiation resistance, with moderate damage resulting at an integrated dose of 5.0×10^7 rad.

5.2 Technical Requirements & Specifications

The primary seal plates and glands conform to ASME 111 subsection NE class MC, but there is nothing specific to elastomers in this code requirement. [Ref. 113]

There are no detailed material requirements for the elastomeric components of the seal assemblies, but in view of the good penetration performance, this does not seem necessary.

5.2.1 Manufacturer testing

The seal gland including cable is subjected to LOCA pressure and temperature transient, and subsequently pressure tested.

The completed penetration assemblies are tested at Bruce after installation by pressurizing the interspace to 83 kPag (12 psig) and checking all joints and sealing gland interfaces with Leak-Tek solution.

Causes of leaks could be:

(1) Primary seal glands leaking
(2) Secondary seal glands leaking
(3) Leakage through embedded part
(4) Leakage at primary seal plate welds (unlikely due to strict NDE procedures)
(5) Leakage at secondary plate gasket

A post-installation leak test is considered satisfactory when:

(1) The penetration can hold, with negligible loss, the test pressure of 83 kPag (12 psig) for about 30 minutes with the air supply shutoff valve closed.

(2) There is no detectable Leak Tek bubbling on any part of the primary seal plate and glands.

(3) There is only minor weeping of air bubbles on any part of the secondary seal plate or glands. Silicone grease can be applied to stop weeping leaks.

The maximum anticipated pressure inside the reactor building is 48 kPag (7 psig). The maximum allowable leakage from the reactor building is divided between the penetrations to allow a total of 3 cfm (cubic feet/minute) at all cable penetrations. [Ref. 114]

5.3 Operational and Environmental Stressors

Environmental conditions vary, depending on the location of the penetration, but are generally similar to those specified for the airlocks, i.e:

Humidity:	95-100%
Radiation fields:	normally <10 mrad/h, i.e. 35 Gy (3.5×10^3 rad) in 40 years
Ozone levels:	1.0 ppm
Normal temperature:	1.7-38°C (35-100°F)
Maximum temperature:	122°C (252°F) (LOCA)
Normal pressure:	-3.4 to -2.0 kPag (-.5 to -.3 psig)
Maximum pressure:	48 kPag (7 psig)

The compressive stress on the gaskets is probably the most significant stressor, under normal operating conditions.

5.4 Operational Testing

CSA Standard N287.7, In-service Examination and Testing Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants (April 1980) applies, in that the organic parts of the containment system (i.e. gaskets) are required to be tested at least yearly, and more frequently if significant deterioration is evident.

All reactor units are pressure tested prior to operation at about 48 kPag (7 psig).

Pickering on-power reactor building pressure tests, to a pressure of 1 kPad have been performed on a quarterly basis as of June 1978, as per Test C-12. [Ref. 115] These tests identify excessive leakage through the total containment boundary, not just through electrical penetrations. At Pickering cable penetration leak testing is accomplished by monitoring the rate of pressurization of the reactor building due to instrument air in-leakage against a standard rate. This allows an "equivalent hole size" to be determined. Hole sizes of about 3.2 cm^2 (0.5 in^2) can be readily detected.In addition, pressure tests at higher pressures, typically 7 to 14 kPa (1 to 2 psi) have been performed occassionally. Refer to Appendix 5.1 for details of testing.

At Pt. Lepreau there is no preventative maintenance on electrical penetrations, but some of the penetrations are visually checked each year. The reactor building pressure test is carried out every five years.

At Bruce, the intent is to test leak tightness of electrical penetrations on a five year cycle, as per Test 4.18. [Ref. 116] Five penetrations are to be tested at a time, by pressurizing the interspace to 70 kPa. To pass the test, the pressure must not drop by more than 35 kPa/hour. There must be no detectable Leak-Tec bubbling on any part of the primary seal plate and glands.

Records of testing at Pickering A, Pickering B, and Bruce A are included in Appendix 5.1. Pickering A and B have excellent testing records, but Bruce A testing is more sporadic. Refer to Section 5.5.2 for an explanation. The routine testing at Pickering is able to detect gross leakage only. Routine testing to higher pressures on at least a five year basis, and a routine inspection schedule is recommended, since leakage from the reactor building in the event of a LOCA is a serious concern.

5.5 Operational Experience

At Pickering, the integrity of cable penetration seals is only determinable when the reactor building is pressurized. Pickering A did not manage to do any reactor building pressurization tests until 1975, due to difficulties with the leak tightness of the pressure relief bulkhead panel.

5.5.1 Summary of Failure Modes and Causes

A likely cause of leakage, and therefore functional failure, is compression set and resultant loss of sealing of the elastomeric gasket in the primary gland seal. Failures detected to date have been minor.

Pt. Lepreau has experienced a small difficulty, in that the silicone gasket in the primary gland was hardening, during the construction period. A lubricant compatible with silicone was applied, and there have been no further problems. [Ref. 117]

5.5.2 Frequency of Failures

A review of the Pickering Quarterly Technical Reports and a Pickering In service Report on Reactor Building leak search tests indicates that although there are small leaks at the penetrations, these are easily repaired by resealing the leaking joints. [Ref. 118] Refer to Appendix 5.2 for data from the Quarterly Technical Reports.

Bruce A has experienced high failure rates of the Electrical Penetration Leak rate Test 4.18. The containment boundary has been found intact, but the fittings on the inside containment side could not be qualified as a positive seal, and will leak under pressure. Accordingly, this test is not being used.

5.5.3 Methods of Detection

Detection of leaks is via the pressurization of the reactor building, and actual location of the leaks is done by applying soapy Leak-Tek solution to the penetration.

5.5.4 Maintenance Actions

Maintenance actions consist largely of lubrication of the silicone seal, leak testing of the penetration, and occassional tightening of the gland seal nuts.

5.5.5. Modifications Resulting from Failures

The design of the cable penetration assembly used for Douglas Point and Pickering A is different from that used at Bruce, in that in the earlier design, the Skycast Epoxy Casting and gland body had only a flat steel washer and a flat silicone rubber washer between them and the stainless steel gland nuts. Sealing within specified limits, i.e. 0.028 cc/s at 0.43 kPa (6.1 in^3/h at 9 psi) was easily achieved initially, but this became more difficult to achieve as the gaskets began to see compression set, and the gland nuts had to be retightened. The dissimilar metals (carbon steel and stainless steel) made the retightening difficult, because of corrosion. A test program was undertaken at AECL which resulted in a 'live loading' of the gland, which is the present design. The Silicone rubber gaskets tested were Dow Corning Type D and GE type 630, but the Dow Corning type D seal did not pass the leak test. The GE 630 seals were subsequently aged at 340°F for 64 hours, and leaks were stopped by adjustment of gland nuts. Thermal cycling tests with both materials did not produce any leaks. [Ref. 119]

At Bruce, a secondary seal plate and gasket were added on the reactor building side of each penetration. This is not considered a containment boundary, but allows the penetration to be leak tested individually, without pressurizing the reactor building. At Pickering and the CANDU 600s, the reactor building has to be pressurized to test penetration leak tightness.

Ontario Hydro is investigating the design of the secondary plate assembly at Bruce and will suggest improvements, so that the cable penetration assembly can be successfully tested.

5.6 Recommended Guidelines for Monitoring Methods and Maintenance

There are very few difficulties experienced with cable penetrations, and leaks are generally very easily repaired with a silicone sealant. In light of this, a detailed review of the elastomeric component, i.e. the gaskets, does not seem to be warranted.

Recommended actions are:

(1) A solution should be found for the secondary side sealing plate leakage at Bruce, so that leak tests can be done on the penetrations.

(2) Testing of the penetrations via pressurization of the reactor buildings at Pickering and the CANDU 600s to about 42 kPa (6 psi) should be done regularly, e.g. at least on a five year basis, to ensure minimum leakage in the event of a LOCA.

D. NON-CANDU EXPERIENCE WITH ELASTOMERS

Several US utilities, the US Nuclear Regulatory Commission, Framatome and the Central Research Institute of Electric Power Industry (CRIEPI) in Japan were contacted for information on their experience with elastomers in pressure boundaries.

1. North East Utilities, USA

North East Utilities, which operates Millstone Unit 1 (BWR, 1970), Unit 2 (PWR, 1975), and Unit 3 (PWR, 1986) has provided information on nozzle dams, and nozzle plugs. These dams are used for isolation during maintenance, e.g. installed in the steam generator primary system nozzles for isolation of the steam generator from the primary system during steam generator cleaning. The aging of the elastomeric components has been addressed for Unit 2 steam generator nozzle dams, and Unit 1 recirculation nozzle plugs. Both are used on a temporary basis only to provide isolation during shutdowns, and are not a permanent part of the systems. They are discarded after use, due to the high radiation exposure during use and the short term testing information. Both seals are of EPDM, (ethylene propylene diene monomer) and are subjected to pressure stress, chemical stress from decontamination solutions, temperatures around 250^{o}F, and high radiation levels.

North East Utilities relies on the manufacturer to provide an estimate of service life. A visual and pressure testing procedure developed by the manufacturer, Combustion Engineering, is used for receipt inspection of the seals. An examination of radiation records is done, to ensure that the material is not overexposed. The North East Utilities contact has stated that, to the best of his knowledge, there are no elastomeric components in permanent pressure boundaries, i.e. airlocks, fuelling related operations, or electrical penetrations. [Ref. 120]

North East Utilities initiated an extensive research program on the aging of cable materials. This has been expanded, and is now sponsored by EPRI, with extra participation from about eight other US utilities. There are about 15 placements of about 6,000 samples in 8 reactors. Materials being tested are:

- EPR, Ethylene Propylene Rubber (EPM and EPDM)
- CSPE, Chloro Sulphonated Polyethylene
- XLPE, Cross Linked Polyethylene
- Neoprene
- Silicone Rubber
- Kapton
- Viton A
- Phenolics

Radiation fields and temperatures are being closely monitored, and testing will include swelling, tensile strength, elongation, modulus of elasticity, density and extraction (liquid chromatography). [Ref. 121]

2. Commonwealth Edison

Commonwealth Edison in the US has the following operating reactors:

Byron-1 (PWR-1985)
Dresden 2 and 3 (BWR-1970, BWR-1971)
LaSalle County 1 and 2 (BWR-1982, BWR-1984)
Zion 1 and 2 (PWR-1973, PWR-1974)
Quad Cities 1 and 2 (BWR-1972, BWR-1972)

Commonwealth Edison has developed an environmental qualification procedure for equipment located in critical areas of the plant. Elastomeric components of equipment, e.g. pump seals, are appropriately aged and irradiated, and then are environmentally tested as part of the equipment. They are not subjected to any kind of scheduled monitoring or surveillance thereafter, but are assumed to perform their function until the scheduled change-out date. The change-out cycle varies, depending on the component and its location, from 1 cycle up to 40 years. All scheduled change-outs are on a computerized data base, which is used by the maintenance department. [Ref. 122]

The seals on the airlock entry into the reactor building are standard weather stripping. The elastomeric seals on the shielded door entry into the drywell are tested after every entry. If the seal passes this leak rate test, it is not replaced. [Ref. 123]

At Quad Cities 1 and 2, the primary containment is provided by the dry well and wet well. The drywell head seal is changed when it appears damaged, or fails its leak rate test. This test is done before the drywell head is removed, and after head replacement, for every outage. This is approximately every 1-1/2 years.

A test program is being developed now for the drywell head seal on BWRs. This is essentially a large gasket, 1.9 x 1.25 cm (3/4"x1/2") thick, with the diameter of the drywell. This seal is presently of Silicone rubber Garlock #8364. It has recently been found that the seal did not provide a leak tight containment seal for the intended 18 months, and the suspected cause is compression set, being influenced by the reactor cooldown rate. Normal operating temperatures are 70°C (158°F). This seal must be able to withstand LOCA conditions. The test program consists of looking at compression set retention and tensile strength in small specimens of four materials following their exposure to a simulated 18 months in-service, and then LOCA conditions.

The samples will be irradiated to 1.44×10^8 rad, which simulates 18 months of exposure (1.6×10^7 rad) and exposure due to a LOCA (1.28×10^8 rad). Materials tested are:

- red silicone rubber, garlock #8364
- red silicone rubber, AMS 3301
- EPDM E603
- Pressray 95A43

The effects of temperature on compression set will also be investigated. [Ref. 124]

3. CRIEPI (Central Research Institute of the Electric Power Industry)

CRIEPI (Japan) has also provided information on their elastomeric seals. Airlock seals are silicone rubber, which are replaced once a year, and leak tested at each regular inspection. It is believed that these seals are gasket-type seals. Seals for the equipment entries into the drywell and Reactor Building are of Neoprene, and are leak tested once a year. Also, if visual inspection reveals an abnormality in these seals, they are replaced. Generally, they are replaced once in two years.

Cable penetration and elastomeric hoses are visually inspected and replaced as required. Further details have not been provided.

There are no seals equivalent to the CANDU concrete joint seals or the main pressure relief valves. [Ref. 125]

E. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

In the United States, there seem to be two approaches which differ from the Canadian approach. First, use of elastomers is eliminated wherever this is feasible. Ontario Hydro appears to be doing the same, with the elimination of the vacuum roof seals at Darlington, and substitution of metal seals in the contraction joints in the pressure relief duct. The second is to thoroughly environmentally qualify the components, and then assume that no further inspection is required. Since the components are generally less critical than some of those considered in CANDU, this is a good idea. It is not recommended for components which are containment boundaries. An Environmental Qualification Program has been implemented for Darlington A, to quantify radiation and thermal aging, cyclic and mechanical wear, and LOCA degradation, in order to determine specific replacement schedules, parts, and materials necessary to maintain the environmentally qualified status of the components.

The following recommendations apply to all elastomeric components considered, and are generally applicable to all elastomeric components in CANDU reactors.

(1) Extreme care should be taken in storage, handling installation and maintenance of all elastomeric parts. In several cases these have been less than perfect, resulting in damage to the part, e.g. vacuum building roof seal installation, storage and replacement of airlock seals, installation of pressure relief duct contraction joints.

(2) Regular visual inspection, at least on a yearly basis, is required for the more critical components, e.g. the vacuum building roof seal, the pressure relief valve diaphragms and the pressure relief duct contraction joints.

(3) Specific guidelines for replacement of selected components should be established and incorporated into a call-up system. This would apply to airlock seals and fuelling machine hoses.

The standards which currently apply to elastomeric materials are not consistent, and are written differently for different components. Some consistency of approach will help in assuring that all necessary factors are considered, before an elastomeric material is chosen for a particular application. The technical specifications are written over a long period of time, and vary greatly in the amount of detail included. With the exception of the replacement vacuum building roof seal, none of them require component testing to ensure survival in post-LOCA conditions.

F. RECOMMENDATIONS FOR FUTURE RESEARCH

The following are recommendations for further work to be done in the area of aging of elastomers.

1. Estimation of the Life-span of Elastomeric Components

Evaluation of the life-span of some of the more critical components of CANDU reactors is important, since it should largely define the replacement program. Unfortunately, there is no practical general methodology which allows prediction of long-term life of a component based on relatively short-term testing. Since the specific compounds of the same elastomers may vary considerably in their properties, the historic experience with the generic types of elastomers is of very limited value.

The theoretical basis for estimating life-span of products exist, for example using an Arrhenius plot of 1/T vs ln (time) which forms a straight line and may be used to extrapolate degradation processes from higher to lower temperatures. Some of these methods are being practically applied to other materials, such as metals. Development of a similar methodology specifically for elastomers is needed. In order to simplify this task, the program should be carried out on one selected critical component, such as the vacuum building roof seal.

Project Objective

To develop the methodology and to evaluate the long-term life of a vacuum building roof seal, based on short-term testing.

Program

(1) review literature on the subject

(2) setup and execute an experimental program

(3) comment on applicability of the methodology to other components

2. Standards

The standards presently used for elastomeric materials are inconsistent and written differently for different elements. A unified set of standards could be expected to improve the safety of the system. A committee consisting of representatives from Ontario Hydro, AECL and the AECB should be formed to produce such a set of standards. An independent consultant or consulting firm should be contracted to coordinate this effort as well as to provide technical consulting to the committee.

The standard could consist of the following components:

(1) classification of components (based on how critical they are)

(2) general material requirements

(3) product requirements (for specific components)

(4) acceptance and quality testing

(5) monitoring and replacement

3. Effect of Dose Rate on Degradation of Elastomers

Most of the elastomers used in CANDU pressure boundary service are subjected to low level radiation. However, most of the specifications consider total dose only, leaving it up to the testing agency to decide on the dose rate. In order to obtain results in short time, high dose rates have to be used. The literature indicates that the degradation process is strongly dependent on radiation rate and therefore reliance on the total dose might result in misleading conclusions. An experimental program is needed to determine the effect of dose rate on the degradation of some of the specific compounds used in CANDU reactors.

Objective

To determine the effect of the dose rate on radiation degradation of elastomeric components used in CANDU boundary service.

Program

(1) conduct a literature review

(2) select and acquire samples of specific materials used in CANDU

(3) develop test methodology and conduct tests

(4) prepare recommendations on how the testing for radiation effects should be written into the standards

4. Degradation Monitoring Methods

Degradation monitoring is used infrequently and sporadically in determining optimum replacement of an elastomeric component. This is partially due to the lack of accurate reliable monitoring techniques. Suggestions have been made

for using alternative techniques. These should be investigated, to determine their feasibility in the operating stations.

- fibre optics inspection of the pressure relief valve diaphragms
- measurement of sealing force on vacuum building roof seals with pressure transducers

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APPENDIX 1

VACUUM BUILDING ROOF SEALS

Note: Appendix Numbering Refers to Subsection Numbers in Chapter C

1.1 Extract from Ontario Hydro Specification for Replacement Vacuum Building Roof Seal

1.2 Record of Testing for Vacuum Building Roof Seal

EXTRACT FROM ONTARIO HYDRO SPECIFICATION
FOR REPLACEMENT VACUUM BUILDING ROOF SEAL APPENDIX 1.1

4.0 TEAR RESISTANCE OF ELASTOMER

4.1 Test specimens to determine the tear resistance of the rubber in the seal shall be prepared in accordance with ASTM D3183 and shall be free from reinforcing fabric.

4.2 The tear resistance shall be determined according to ASTM D624. Test specimens shall conform in shape to Die B.

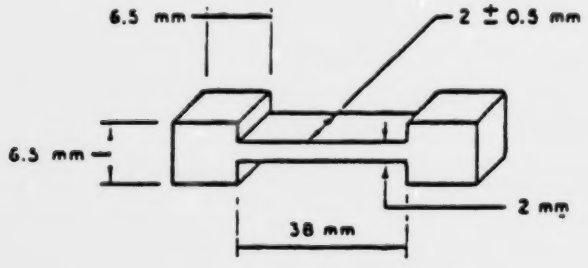
5.0 STIFFNESS TEMPERATURE OF ELASTOMER

5.1 The specimen for the test shall be of the same dimensions and obtained in the same manner as for the Ozone Resistance test, Appendix 6.1. The test shall be performed under conditions meeting ASTM D832.

5.2 The T_2 stiffness temperature shall be determined according to ASTM D1053.

6.0 OZONE RESISTANCE

6.1 Specimens for the test, eleven in all, prepared from the seal with a suitable die, shall be of the design and dimensions shown below:



6.2 With one specimen maintained at zero elongation and each of the remaining maintained respectively at elongations of 5, 10, 15, 20, 25, 30, 40, 50, 75 and 100 percent. All specimens shall be exposed to ozone at a concentration of 0.5 μL/L at 38°C for 500 hours. The test data shall be plotted with the logarithm of the time to failure on the abscissa against the percent elongation on the ordinate.

6.3 In order to evaluate the test data, the graph shall be included with the tendering document.

6.4 Any evidence of cracking, within the specified exposure period, of the 0, 5, 10, 20 percent elongation specimens, shall be taken to constitute failure. The ozone-test chamber and associated apparatus shall be as specified in ASTM D1149.

7.0 ACCELERATED AGING

7.1 Retention of Handleability

7.1.1 Test specimens shall be as specified in Appendix 3.1 for tensile strength of elastomer, as specified in Appendix 4.1 for tear resistance of elastomer, and as specified in Appendix 5.1 for stiffness temperature.

7.1.2 Age all test specimens for 168 hours at 125°C in an air circulating oven, meeting the requirements of ASTM D573.

7.1.3 After the aging period is completed, remove test specimens from the oven, cool to room temperature and measure the tensile strength as per Appendix 3.2, the tear strength as per Appendix 4.2 and stiffness temperature as per Appendix 5.2.

8.0 RETENTION OF SEALING BACK-FORCE

8.1 General

8.1.1 The material shall be tested as specified in ASTM D1390, except as described below.

8.1.2 Four specimens of full-thick sections of the seal shall be taken from the clamping area and tested.

8.1.3 The test specimens shall be aged for 168 hours at 125°C in an air circulating oven meeting the requirements of ASTM D573, and for 168 hours at -20°C in a cabinet meeting the requirements of ASTM D832.

8.1.4 The Sealing Back-Force after aging shall be measured at -20°C and at 20°C.

8.2 Test Conditions

8.2.1 Initial Deformation of Test Specimen: The specimen shall be deformed initially to 15 percent compression.

8.2.2 Compressing Testing Machine: The machine shall be capable of having a testing speed of 0.5 mm/min.

8.3 Procedure

8.3.1 Apply the external load to the load applicator at a rate of approximately 30 mm/h.

8.3.2 The use of a stopwatch is optional.

8.3.3 After the bolts have been tightened on the apparatus and the external load has been reduced to zero, allow the assembled apparatus to age for 24 hours at ambient room conditions of temperature and pressure.

8.3.4 After the 24 hour aging period, re-apply the load at a rate of approximately 30 mm/h until the first change in electrical resistance is observed.

8.3.5 Stop the machine at this point, and hold this deflection for 10 minutes ± 10 seconds.

8.3.6 Record the reading as initial backstress S_I. Allow the assembled apparatus to remain at room temperature for 60 ± 5 minutes and then place it in the aging oven, Appendix 8.1.3.

8.3.7 Following the completion of the specified oven and low temperature aging period, see Appendix 8.1.3, re-install the apparatus in the testing machine at -20°C and apply an external load at the rate of approximately 30 mm/h until the first change in electrical resistance is observed.

8.3.8 Stop the machine at this point and hold this deflection for 10 minutes ± 10 seconds. Record the reading as final backstress S_{F-20}.

8.3.9 Calculate the retention of sealing back-force at -20°C as follows:

Retention of Sealing Back-Force, at -20°C = $S_{F-20}/S_I \times 100$ (percent). (This is the effect of low temperature after accelerated aging.)

8.3.10 Raise the temperature of the assembled apparatus to 20°C and maintain it at this temperature for one hour minimum.

8.3.11 Apply an external load at the rate of approximately 30 mm/h until the first change in electrical resistance is observed.

8.3.12 Stop the machine at this point and hold this deflection for 10 minutes ± 10 seconds. Record the reading as final backstress S_{F20}.

8.3.13 Calculate the retention of Sealing Back-Force at 20°C as follows:

Retention of Sealing Back-Force, at 20°C = S_{F20}/S_I x 100 (percent). (This is the effect of accelerated aging.)

9.0 STABILITY OF ELASTOMER UNDER VACUUM

9.1 Tensile test specimens of the elastomer cover shall be prepared as described in Appendix 3.1.

9.2 The test specimens shall be aged for 28 days at 70°C under 101 of vacuum. The specimens shall be cooled to room temperature before testing.

9.3 The ultimate elongation shall be performed as described in Appendix 3.2.

9.4 The durometer hardness shall be determined, in accordance with the requirements of ASTM D2240, with a Type A-2 Shore Durometer. An instantaneous reading shall be recorded.

10.0 COMPLIANCE OF SEAL TO SEISMIC INDUCED MOVEMENTS

10.1 A 1 m length of seal, with a splice located at mid-point, shall be mounted on an assembly representative of the attachment system which occurs on the vacuum building and which mates the design of the seal. The assemblies are illustrated below:

10.2 The seal shall be subjected for 15 seconds to a horizontal, longitudinal (shear) displacement of 4 cm at a rate of 1 Hz, and to a vertical displacement of 2 mm at a rate of 20 Hz, simultaneously applied.

10.3 The maximum force required to achieve these movements shall be recorded.

10.4 Following the movements, the seal shall be examined by an x-ray examination or other destructive or non-destructive techniques for tears, walkout and other damage.

11.0 CREEP OF SEAL UNDER VACUUM LOAD

11.1 A 50 cm section of seal shall be mounted as described in Appendix 10.1 and suspended vertically, as in service, under a load equivalent to that applied by the vacuum building (ie: -101 kPa gauge), and at 70°C, for 12-1/2 days. A second section of seal shall be loaded at two times the design load.

11.2 The extension of the seal shall be measured periodically over the exposure period.

11.3 Following the exposure the seal shall be examined as described in Appendix 10.4 for tears, walkouts or other damage.

11.4 The creep of the seal shall be plotted on the ordinate with duration of load on the abscissa.

12.0 STABILITY OF SEAL UNDER ATTACHMENT LOADS

12.1 Durometer Hardness

12.1.1 The durometer hardness shall be determined, in accordance with the requirements of ASTM D2240, with a Type A-2 Shore Durometer. An instantaneous reading shall be recorded.

12.2 Compressibility of Seal

12.2.1 For Pickering NGS Seal

12.2.2 Determine the effect of bolt torque on the compression of the seal by ASTM F145 when the seal is installed on a sectional unit of the clamping flange assembly, Appendix 10.1. By means of solder plugs determine the distribution of compression between adjacent bolts at 60 N·m, 120 N·m and 180 N·m.

12.2.3 Present data by plotting percentage compression on the ordinate against schematic position of the solder plugs in the seal on the abscissa.

12.2.4 The seal shall be examined for signs of delamination, tear, walkouts or other damage induced by the applied loads.

12.3 For Bruce NGS Seals

12.3.1 A 30 cm section of the seal shall be mounted in an assembly representative of the attachment system which occurs on the vacuum building. A sealing load equivalent to that applied on the structure by the tendons, (ie, 5.6 kN/m of seal length) shall be applied to each of the tendons.

12.3.2 By means of the solder plug technique of ASTM F145 determine the distributions of compression applied across the seal by the tendons.

12.3.3 Present data by plotting percentage compression on the ordinate against schematic position of the solder plugs in the seal on the abscissa.

12.3.4 The seal shall be examined for signs of delamination, tear, walkout or other damage induced by the applied loads.

13.0 EXPOSURE OF SEAL TO ACCIDENT ENVIRONMENTS

13.1 Resistance of Seal to Steam

13.1.1 The inside surface of the central section of the seal shall be exposed to steam at atmospheric pressure and at 100°C for 28 days while mounted on assemblies similar to those illustrated in Appendix 10.0. The opposite side of the seal shall be exposed to atmosphere at 20°C.

13.1.2 Following exposure the seal shall be examined for signs of delamination, softening or other deterioration.

13.1.3 Following the examination, four tensile test specimens of full-thick sections shall be taken from the steam exposed central section of the seal by the procedure described in ASTM D3183. The tensile specimens and measurement of tensile properties shall be performed as described in ASTM D378, but without removal of any cover rubber.

13.1.4 The tensile properties (strength and ultimate elongation) of four identical but unexposed specimens shall be determined as described in Appendix 13.1.3 and the data taken as the control set for estimating the effect of the steam exposure.

13.2 Resistance of Seal to Gamma Irradiation

13.2.1 Retention of Tensile Properties of Seal

13.2.1.1 Tensile test specimens of full thick sections shall be prepared as described in Appendix 13.1.3 but from unexposed seal.

13.2.1.2 The four tensile test specimens shall be exposed to 10 Mrads of radiation at 100 ± 5°C. A second set of test specimens shall be aged in an air oven (ASTM D573) at the irradiated temperatures and for a period of time equivalent to the irradiation period.

Note: The usefulness of these measurements is enhanced when additional specimens are irradiated and oven aged at 0.1 Mrads and 1 Mrads.

13.2.1.3 The tensile properties (strength and ultimate elongation) of the treated test specimens shall be determined as described in Appendix 13.1.3.

13.2.1.4 The test data from Appendix 13.1.4 may be taken as the control set for estimating the effect of the irradiation.

13.2.2 Retention of Sealing Back-Force

13.2.2.1 General

(a) The test specimen shall be a full-thick section of the seal taken from the clamping area and tested as specified in ASTM D1390, except:

(b) Four (4) test specimens shall be irradiated in the cobalt bomb at the test temperature and an identical number of specimens shall be oven aged as thermal controls at the test temperature.

(c) Four of the assembled test specimens shall be exposed to 10 Mrads of radiation at 100 ± 5°C. The second set of four assembled test specimens shall be aged in an air oven (ASTM D573) at the irradiated temperature and for a period of time equivalant to the irradiation period.

Note: The usefulness of these measurements is enhanced when additional specimens are irradiated and oven aged at 0.1 Mrads and 1 Mrads.

(d) The Sealing Back-Force shall be measured at 75°C and at 20°C after the irradiation or thermal aging exposure.

13.2.2.2 Test Conditions

(a) Initial Deformation of Test Specimen. The specimen shall be deformed initially to 25 percent compression, ie, 75 percent of initial thickness shall remain.

(b) Compression Testing Machine. The machine shall be capable of having a testing speed of 0.5 mm/min.

13.2.2.3 Procedure

(a) Apply the external load to the load applicator at a rate of approximately 30 mm/h.

(b) The use of a stopwatch is optional.

(c) After the bolts have been tightened on the apparatus and the external load has been reduced to zero, allow the assembled apparatus to age for 24 hours at ambient room conditions of temperature and pressure.

(d) After the 24 hour aging period, re-apply the load at a rate of approximately 30 mm/h until the first change in electrical resistance is observed.

(e) Stop the machine at this point, and hold this deflection for 10 minutes $\pm$ 10 seconds.

(f) Record the reading as initial backstress S_I.

(g) Allow the assembled apparatus to remain at room temperature for a minimum of 60 mintues and then place it in the aging oven or the cobalt bomb for irradiation. For the thermal control specimens, this period shall include the time (at room temperature) taken to ship the test jig to the cobalt bomb.

(h) Following the completion of the specific aging or irradiation period, see Appendix 13.2.2.1(c), permit the apparatus to cool at room temperature for a minimum of five hours. For the thermal control specimen this period shall include the time (at room temperature) taken to return the test jig to the laboratory from the cobalt bomb.

(i) Re-install the apparatus in the testing machine at 75°C. Wait until the centre of the test specimen has reached this temperature, then apply an external load at the rate of approximately 30 mm/h until the first change in electrical resistance is observed.

(j) Stop the machine at this point and hold this deflection for 10 minutes ± 10 seconds. Record the reading as final backstress S_{F75}.

(k) Calculate the retention of sealing back-force at 75°C as follows:

(l) Retention of Sealing Back-Force, at 75°C =

$$\frac{S_{F75}}{S_I} \times 100 \text{ (percent)}$$

(m) Lower the temperature of the assembled apparatus to 20°C and maintain it at this temperature for 5 ± 1/2 hour.

(n) Apply an external load at the rate of approximately 30 mm/h until the first change in electrical resistance is observed.

(o) Stop the machine at this point and hold this deflection for 10 minutes ± 10 seconds. Record the reading as final backstress S_{F20}.

(p) Calculate the retention of Sealing Back-Force at 20°C as follows:

Retention of Sealing Back-Force, at 20°C =

$$\frac{S_{F20}}{S_I} \times 100 \text{ (percent)}$$

Table 1.1-1: Requirements for Vacuum Building Roof Seal

Seal strength:	88 kN/m minimum (503 lb/in)
Splice efficiency of Joints:	60% minimum
Tensile strength:	10 MPa minimum (1450 psi)
Tear resistance:	35 kN/m minimum (200 lb/in)
Stiffness temperature:	-35°C (-31°F) maximum
Retention of sealing backforce:	20% minimum @ 20°C (68°C)
(After aging)	10% minimum @ -20°C (-4°F)
Stability under vacuum:	A-2 durometer hardness of 60 ± 10; ultimate elongation of 300% minimum
Seismic induced movements:	No walkout, tears or other damage @ 4 cm (1.6 in) displacement
Creep under vacuum load:	5% max @ design load 7% max @ 2X design load Stabilization of creep within 28 days. No tears, walkout etc.
Stability under attachment loads:	A-2 60 ± 10 durometer hardness
Resistance to steam at atmospheric pressure and 100°C for 28 days:	No tears,walkout etc. Tensile strength & ult. elongation to be within 5% of initial values
Resistance to Radiation:	Tensile properties within 5% of initial. Sealing back force retention 40% min. at 75°C (167°F) and 20% min. @ 20°C (68°F)
Ozone resistance:	Shall remain crack free
Accelerated aging:	See tensile strength, tear resistance, stiffness temperature

APPENDIX 1.2

RECORD OF TESTING FOR VACUUM BUILDING ROOF SEAL

Table 1.2-1: Pickering Vacuum Building Inspection Test Performed Once/Shift (Test 45)

	% Complete	
1977	100	New test in 1977
1978	95	
1979	98	
1980	100	
1981	100	
1982	100	
1983	100	
1984	100	
1985	100	Shifts changed to two/day

Table 1.2-2 Bruce A Vacuum Building Leak Rate Test Performed Monthly (Test 4.17)

	% Complete	
1976	0	Intent was to start testing
1977	0	October 29, 1976
1978	0	
1979	0	
1980	100	
1981	96	
1982	100	
1983	98	
1984	96	
1985	100	

Bruce B has been issuing QTRs since 1984, but since this involves only three complete years of testing, records are not included here.

APPENDIX 2

PRESSURE RELIEF DUCT SEALS

Note: Appendix Numbering Refers to Subsection Numbers in Chapter C

2.1 Pressure Relief Duct Airlock Seals - Extracts from Quarterly Technical Reports

2.2.1 Diaphragm Hardness Change with Temperature

2.2.2 Pressure Relief Valve Testing

2.2.3 Pressure Relief Valves - Extracts from Quarterly Technical Reports

2.4.1 Extracts from Ontario Hydro Specification L-984M-79 for Elastomeric Seals for Contraction Joints in Pressure Relief Ducts

2.4.2 Contraction Joints - Extracts from Quarterly Technical Reports

APPENDIX 2.1

PRESSURE RELIEF DUCT AIRLOCK SEALS - EXTRACTS FROM QUARTERLY TECHNICAL REPORTS

Pressure Relief Duct Airlock Seals

Pickering A

4th Qtr, 1973: Low ambient temperatures around pressure relief duct and boiler room airlocks have embrittled neoprene seals so they would not deflate properly. Heaters were installed on these airlocks, and low temperature resistant Si (Silicone) seals were installed on the pressure relief duct airlock as a trial. Initial operating experience was reported as favourable.

1974: 2 seal leakages reported, seals replaced
1975: 1 seal rupture, seals replaced
1976: 2 seal leakages, seals replaced
1977: 2 seal leakages, seals replaced
1978: no reported seal failure

2nd Quarter, 1979: Personnel (AL1) and equipment (AL2) airlock seals were modified, so each airlock is supplied from a different air header and air supply line to each airlock was duplicated. The air receiver was moved to the pressure relief valve weather enclosure, to reduce the probability of ice forming in the supply line.

3rd Quarter, 1979: 1 seal, outer door AL2 leaking

1980: no reported seal failure
1981: no reported seal failure
1982: 3 seal failures
1983: 1 seal failure
1984: no reported seal failure
1985: no reported seal failure

<u>Actual Unavailability of Pressure Relief Duct Airlock</u>

1977 $.68 \times 10^{-3}$
1978 0 predicted .02
1979 0
1980 0
1981 0
1982 0
1983 0
1984 0
1985 0

APPENDIX 2.2.1

DIAPHRAGM HARDNESS CHANGE WITH TEMPERATURE

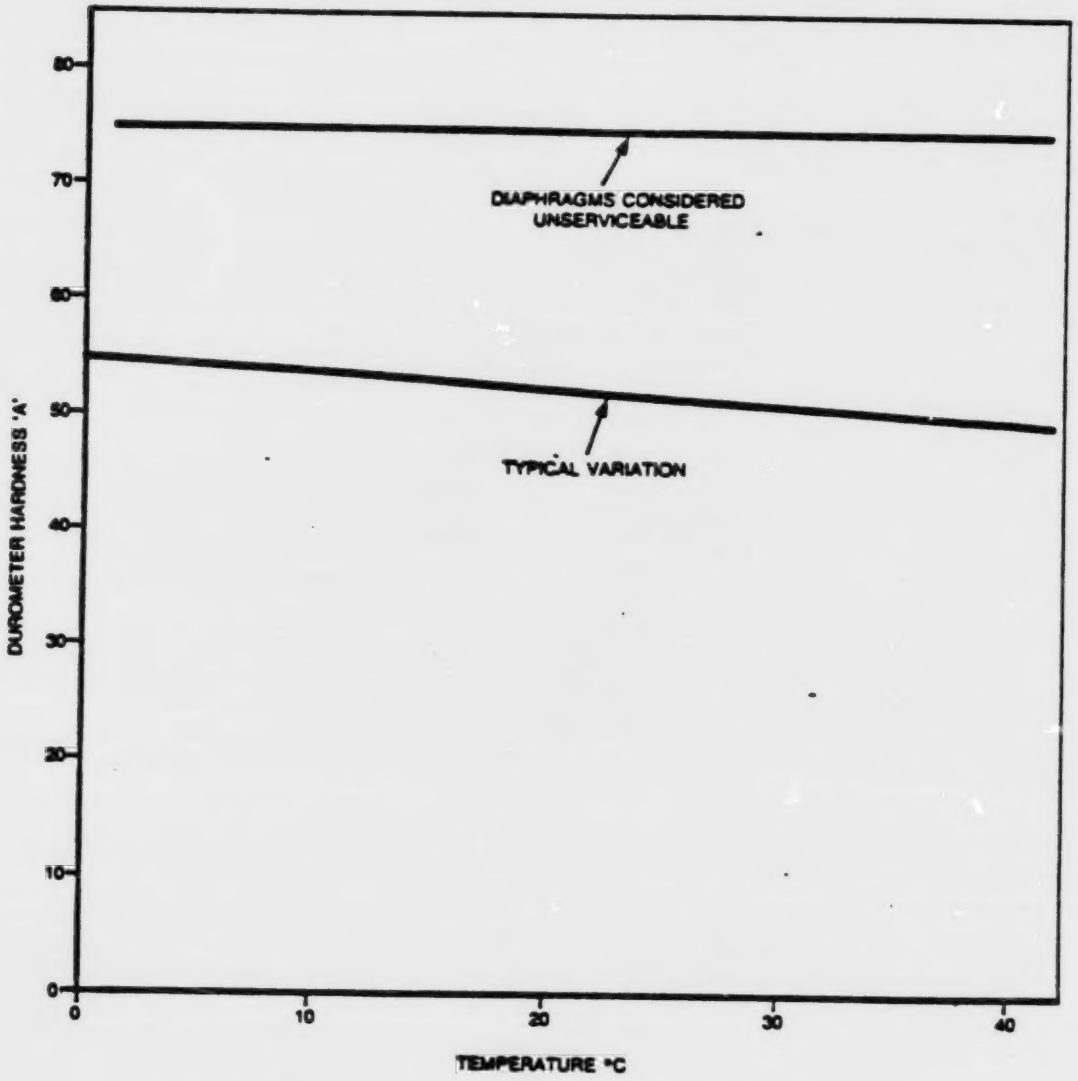


Figure 2.2.1-1: Rolling Diapragms, Hardness change with Temperature for EPDM rubber

(Ref. AECL Design Description 30-34210-5A)

APPENDIX 2.2.2

PRESSURE RELIEF VALVE TESTING

Table 2.2.2-1: Pickering Pressure Relief Valve Test
Test 25

	Target one valve/wk	Actual	% Complete
1972	52	29	56
1973	52	35	67
	one valve/mth		
1974	12	12	100
1975	12	12	100
1976	12	12	100
1977	12	12	100
1978	12	11	92
1979	12	11	92
1980	12	12	100
1981	12	12	100
1982 PRV Check(25A)	12	12	100
IPRV Check(25B)	12	12	100
1983 25A			100
25B			100
1984 25A			100
25B			100
1985 25A			100
25B			100

Table 2.2.2-2: Bruce A Pressure Relief Valve Testing

Main Pressure Relief Valve Test (Test 4.8)

Intended frequency: Each valve tested yearly, 16 valves/year
Frequency changed to 4 valves/year in '86

	% Complete	
1978	25	
1979	100	All tested, following addition of retainer ring
1980	100	
1981	87	14 pressure relief valves tested, PRV17 found faulty
1982	0 }	Due to PRV17 blow through incident
1983	0 }	Approved work practices required
1984	0	Due to new test instrumentation being installed
1985	100	

Table 2.2.2-3: Bruce A Pressure Relief Valve Inspection Test 4.9 and 4.10

Intended frequency: 26 times/year

	PRVs East (4.9) % Complete	PRVs West (4.10) % Complete
1978	92	96
1979	100	85
1980	92	100
1981	96	96
1982	100	100
1983	0	0
1984	100	100
1985	100	100

APPENDIX 2.2.3

PRESSURE RELIEF VALVES - EXTRACTS FROM QUARTERLY TECHNICAL REPORTS

Pressure Relief Valves

Pickering

1971: During a routine test, observed that the pressure relief valve lower diapragm was developing minor cracks, and operations decided to replace the diaphragms before the cracks got larger. On valve 0-3421 PRV8, one of the five layers of rubber was split along a length of 18", and none of the fibre reinforcing layers were split. The split was repaired using a rubber cement, not replaced.

1st Quarter, 1972: Possible signs of water or ice were detected on 3421-PRV1. The lower seating O-ring to the lower diaphragm of the valve was leaking, but the leak sealed itself when vacuum was drawn on the valve.

1973: No significant events

1st Quarter, 1974: Difficulty maintaining vacuum building vacuum due to leakage past O-ring seals under 2 pressure relief valves. Seals lost resilience due to aging and low ambient temperature. Seals were replaced, and radiant heaters were installed in the relief duct.

1975: No significant events
1976: "
1977: "
1978: "

1st Quarter, 1979: A routine pressure test was done on 3421-PRV2, and following the test, pressure under PRV2 could not be reduced. An O-ring on PRV2 was found to be leaking. Testing of the valve in cold weather had caused the O-ring seal to be disturbed due to movement of the valves and hardened rubber seals. Attempts to seal the leak with RTV were unsuccessful due to the large area to be sealed, and extreme cold temperatures in the duet, i.e. -7°C. The pressure relief valve was isolated and removed from service.

2nd Quarter, 1979: The conclusion of a report on the in-service inspection of the vacuum building was that one of the most likely sources of vacuum building air in-leakage is the pressure relief valves, due to deterioration of rubber seal components. All valves were recommended to be overhauled and worn seals replaced in the near future. Two or three of the pressure relief valves have significant leakage at the receptacle flange O-ring seal.

4th Quarter, 1979: An air leak was observed from PRV1. The diaphragm was replaced.

1st Quarter, 1980: An O-ring on PRV2 was leaking, and was replaced. This required isolating the valve for 58 hours.

2nd Quarter, 1980: An inspection of seals and diaphragms on a number of pressure relief valves was made, for cracks and hardness. The hardness of the diaphragms had increased by up to 21 Durometer A since 1970.

1982-1985: no reported incidents

2nd Quarter, 1984: Hardness measurements were made on the diaphragms of one pressure relief valve. No significant change in hardness was found since 1980.

Table 2.2.3-1: Bruce A Actual Unavailability, Pressure Relief Valves

	Bruce A	Bruce B
1976	2.74×10^{-3}	
1977	0	
1978	N/A	
1979	12.96	
1980		
1981	0	
1982	0.46	
1983	0	
1984	0	N/A
1985	0	APRVs 0 IPRVs 0

EXTRACTS FROM ONTARIO HYDRO SPECIFICATION L-984M-79
FOR ELASTOMERIC SEALS FOR CONTRACTION JOINTS IN PRESSURE RELIEF DUCTS

5 TEST AND TEST PROCEDURES

5.1 Tensile Properties of the Elastomer Cover

5.1.1 Test specimens shall be obtained by the procedures outlined in ASTM D3183 and shall be free from reinforcing fabric.

5.1.2 Tests for tensile strength and ultimate elongation at break shall be performed in accordance with the procedures specified in ASTM D1708 except:

(i) the gripping surfaces of the jaws shall be smooth and flat;

(ii) the gripping pressure of the jaws shall be 500 ± 20 kPa;

(iii) the testing speed shall be between 1.7 mm/s and 2.0 mm/s.

5.2 Tear Resistance

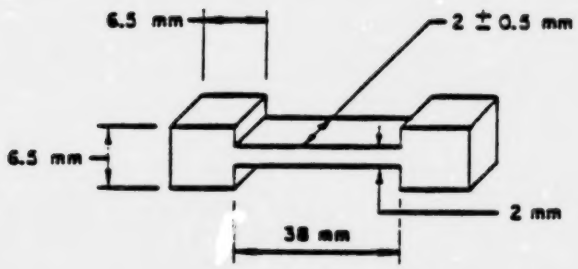
5.2.1 Test specimens to determine the tear resistance of the cover rubber shall be prepared in accordance with ASTM D3183. The test specimens shall be free from reinforcing fabric.

5.2.2 The tear resistance shall be determined according to ASTM D624. Test specimens shall conform in shape to Die B.

5.3 Durometer Hardness Specimens of the cover rubber shall be tested. The tests for Durometer Hardness shall be performed in accordance with ASTM D2240.

5.4 Ozone Resistance

5.4.1 Specimens for the test, 14 in all, prepared with a suitable die from the seal cover, shall be of the design and dimensions shown below:



5.4.2 With one specimen maintained at zero elongation and each of the remainder maintained respectively at elongations in increments of 5 per cent up to and including 30 per cent elongation, then in increments of 10 per cent up to and including 100 per cent elongation, all specimens shall be exposed to ozone at a concentration of 0.5 µL/L (0.5 ppm) at 38°C for 500 h (hours). The test data shall be plotted with the logarithm of the time to failure on the abscissa against the per cent elongation on the ordinate.

5.4.3 In order to evaluate the test data, the graph shall be included with the supplier's tender.

5.4.4 Any evidence of cracking, within the specified exposure period for the 0 to 100 per cent elongation specimens, shall be taken to constitute failure. The ozone-test chamber and associated apparatus shall be as specified in ASTM D1149.

5.5 Compression Set

5.5.1 Four (4) test specimens shall be tested. Each test specimen shall consist of two (2) seal sections of full thickness plied together.

5.5.2 Test specimens shall be aged for 22 h at 175 ± 5°C.

5.5.3 The tests for Compression Set shall be performed in accordance with ASTM D395, Method B for constant deflection.

5.6 Resistance to Pull-Out

5.6.1 Test Specimens Test specimens shall be taken from a full width section of a seal and shall be 460 mm long. Three holes of 17.5 mm diameter shall be punched into each specimen on 152 mm centers at a distance of 32 mm from the edge cap side of the specimens. The two sets of three holes shall be aligned to fit the clamping fixture.

5.6.2 Test Apparatus

5.6.2.1 The clamping fixture shall simulate the attachment features of the rectangular contraction joint.

5.6.2.2 Steel plates 9.5 mm thick, 508 mm long and 76 mm wide shall be drilled with 19.0 mm diameter holes at 152 mm centers. (The location of the holes shall match those of the holes in the test specimens). The holes shall be located 45 mm from the clamp edge on the side facing the free seal.

5.6.2.3 The clamping fixtures at each end shall be identical and symmetrical. One clamping fixture shall be attached to a stationary support, the other to a pan to contain the loads for simulating a vacuum load.

5.6.3 Test Procedure

5.6.3.1 Assemble the apparatus by installing the seal sample specimen between the clamping fixtures with 5/8 inch bolts tightened with a torque of 67.8 N·m.

5.6.3.2 Install a mass of 470 kg in the pan of the suspended apparatus and expose the complete assembly to 32°C for 28 d (days).

5.6.3.3 Examine the test specimen after initial loading and after the 28 d test period for signs of delamination, disintegration, tearing within the seal and movement of cords into the reinforcing fabric especially in areas adjacent to the bolt holes.

NOTE

An X-ray examination of the embedded fabric may be used to confirm the stability of the seal under these loading and exposure conditions.

5.6.3.4 Any signs of deterioration, change or damage to the seal or cord movement within the fabric shall constitute failure.

5.7 Accelerated Aging, Effects of

5.7.1 Test Specimens Test specimens shall be prepared as follows:

5.7.1.1 Test specimens shall be as specified in para. 5.1 for change in tensile strength and ultimate elongation.

5.7.1.2 Full sections of the seal 50 mm by 100 mm in size shall be prepared for change in mass and durometer hardness.

5.7.2 Procedure

5.7.2.1 Measure the mass of four (4) test specimens prepared according to para. 5.7.1.2 and calculate the average value.

5.7.2.2 Age all test specimens for 70 h at 230°C in an air-circulating oven, meeting the requirements of ASTM D573.

5.7.2.3 After the aging period is completed, remove test specimens from the oven and measure the tensile properties - as per para. 5.1, durometer hardness - as per para. 5.3, and mass - as per para. 5.7.2.1.

5.7.2.4 Calculate the change in tensile properties, durometer hardness and mass due to accelerated aging.

5.8 Retention of Sealing Back-Force

5.8.1 General The material shall be tested as specified in ASTM D1390, except.

5.8.1.1 Four (4) test specimens shall be tested. Each test specimen shall consist of two seal sections of full thickness plied together.

5.8.1.2 The assembled test specimens shall be aged for 168 h at 125 ± 5°C.

5.8.1.3 The Sealing Back-Force shall be measured after the aging exposure at 22°C and at -20°C.

5.8.2 Test Conditions

5.8.2.1 Initial Deformation of Test Specimen The specimen shall be deformed initially to 25 per cent compression.

5.8.2.2 Compression Testing Machine The machine shall be capable of having a testing speed of 0.5 mm/min.

5.8.3 Procedure

5.8.3.1 Apply the external load to the load applicator at a rate of approximately 30 mm/h.

5.8.3.2 The use of a stopwatch is optional.

5.8.3.3 After the bolts have been tightened on the apparatus and the external load has been reduced to zero, allow the assembled apparatus to age for 24 h at room ambient conditions of temperature and pressure.

5.8.3.4 After the 24 h aging period, re-apply the load at a rate of approximately 30 mm/h until the first change in electrical resistance is observed.

5.8.3.5 Stop the machine at this point, and hold this deflection for 10 min ± 10 s.

5.8.3.6 Record the reading as initial backstress S_I.

Allow the assembled apparatus to remain at room temperature for 60 ± 5 min and then place it in the aging oven.

5.8.3.7 Following the completion of the specified aging period, see para. 5.8.1.2, permit the apparatus to cool at room temperature for 5 ± 1/2 h.

5.8.3.8 Re-install the apparatus in the testing machine and apply external load at the rate of approximately 30 mm/h until the first change in electrical resistance is observed.

5.8.3.9 Stop the machine at this point and hold this deflection for 10 min ± 10 s. Record the reading as final backstress $S_{F_{22}}$.

5.8.3.10 Calculate the retention of sealing back-force at 22°C as follows:

$$\text{Retention of Sealing Back-Force, at 22°C} = \frac{S_{F_{22}}}{S_I} \times 100 \text{ (per cent)}$$

5.8.3.11 Lower the temperature of the assembled apparatus to -20°C and maintain it at this temperature for 1 h minimum.

5.8.3.12 Apply external load at the rate of approximately 30 mm/h until the first change in electrical resistance is observed.

5.8.3.13 Stop the machine at this point and hold this deflection for 10 min ± 10 s. Record the reading as final backstress $S_{F_{-20}}$.

5.8.3.14 Calculate the retention of Sealing Back-Force at -20°C as follows:

$$\text{Retention of Sealing Back-Force, at } -20°C = \frac{S_F\text{-}20}{S_I} \times 100 \text{ (per cent)}$$

6 QUALITY ASSURANCE PROVISIONS

6.1 The inspection requirements of Ontario Hydro A-1 shall apply.

6.2 The supplier shall provide Ontario Hydro, prior to shipment of the seals, with certified data to show adequate quality control of materials and processes associated with the manufacture of the seal. These data shall include the results of the tests listed in the Table.

6.3 The authorized representative of Ontario Hydro shall be afforded, without charge, reasonable access to witness quality control testing, manufacturing processes, and the preparation of sample splices, to ensure that the materials and methods are in accordance with this specification.

6.4 Ontario Hydro reserves the right to select samples of seals intended for shipment to fill the purchase order that accompanies this specification, and to conduct tests for all characteristics in accordance with the requirements of this specification.

6.5 Splicing techniques used in the factory and at the job site shall be identical to those demonstrated to Ontario Hydro (see para. 3.3) and in all instances shall be satisfactory to the authorized representative of Ontario Hydro. Splicing shall be performed without causing any unnecessary damage to the original cover elastomer and reinforcement fabric materials in the area of the splice.

6.6 Failure of any seal to conform to any or all requirements of this specification shall constitute cause for rejection of the seal length represented.

	PROPERTY OF SEAL	REFERENCE PARA.	UNITS	REQUIREMENT
1	Initial Properties			
1.1	Cover Rubber			
1.1.1	Tensile Properties - tensile strength - ultimate elongation	5.1	MPa per cent	7 minimum 250 minimum
1.1.2	Tear Resistance	5.2	kN/m	16 minimum
1.1.3	Durometer Hardness	5.3	A-2	65 ± 5
1.1.4	Ozone Resistance	5.4	-	pass
1.2	Seal			
1.2.1	Compression Set	5.5	per cent	20 maximum
1.2.2	Resistance to Pull-Out	5.6	-	no signs of deterioration change or damage to seal or cord movement
2	Effects of Accelerated Aging			
2.1	Cover Rubber			
2.1.1	Tensile Properties - tensile strength - ultimate elongation	5.7	per cent per cent	-20 max. of original value -20 max. of original value
2.1.2	Durometer Hardness	5.7	A-2	$^{+4}_{-0}$ max. of original value
2.1.3	Change in Mass	5.7	per cent	3 max. of original value
2.2	Seal			
2.2.1	Retention of Sealing Back-Force @ +22°C @ -20°C	5.8	per cent per cent	40 minimum 35 minimum
3	Dimensions (Seal)			
3.1	Length joint tab		m -	as specified pass
3.2	Width		cm	38 ± 0.6
3.3	Overall thickness		cm	0.50 minimum
3.4	Even thickness of cover rubber		-	pass
3.5	Edge Cap thickness		cm	0.6 ± 0.1
3.6	Seal Surface Gradient		-	1 mm maximum in 300 mm length
4	Seal Surface Quality		-	pass
5	Splice			
5.1	Stability on Bending		-	pass
5.2	Surface Quality and Alignment		-	pass

APPENDIX 2.4.2

CONTRACTION JOINTS - EXTRACTS FROM
QUARTERLY TECHNICAL REPORTS

Pickering A

2nd Quarter, 1980:The expansion joints in the pressure relief duct were examined, and found to be in "as new" condition. There were no blemishes, walkout, cracking, or any signs of deterioration or aging.

3rd Quarter, 1980:During routine on power pressure test, leaks were found in pressure relief duct construction joints. Leaks were subsequently repaired. The leak was not serious, i.e. equivalent estimated hole size was 1000 mm^2.

1st Quarter, 1987:A five year periodic inspection of the duct was done. The duro-hardness was measured and a visual inspection done.

APPENDIX 3

AIRLOCK SEALS

Note: Appendix Numbering Refers to Subsection Numbers in Chapter C

3.1 Extract from Ontario Hydro Specification L-62SM-82, Inflatable Seals for Doors of Containment and Confinement Areas.

3.2 Airlock Seal Inspection and Testing

3.3 Airlock Unavailability and Failure Rate Data

EXTRACT FROM ONTARIO HYDRO SPECIFICATION L-625SM-82
INFLATABLE SEALS FOR DOORS OF CONTAINMENT AND CONFINEMENT AREAS

6 TEST AND TEST PROCEDURES

6.1 General: Tests shall be done to demonstrate conformance with the requirements listed in Table I at the end of this specification.

6.2 Testing Schedule and Responsibility

6.2.1 Testing shall be done in order to provide the qualification data specified in section 3.1. In addition testing of production items must be done per section 8.

6.2.2 Testing of collapse time as noted in para 6.4.7 may be carried out on a prototype only, if agreed to by Ontario Hydro.

6.3 Tests on Elastomer

6.3.1 Tensile and ultimate elongation tests shall be carried out on micro-specimens, prepared as described in ASTM D3183, from the striker head material after vulcanization. The specimen dimensions shall be those given in ASTM D1708. The test requirements shall be those covered by ASTM D412.

6.3.2 Tear-strength measurements shall be done in accordance with ASTM D624 requirements, using specimens prepared with Die B.

6.3.3 For determination of stability under high-energy nuclear radiation, micro-specimens from the striker head material, hung on a suitable frame in such a manner as to be totally surrounded by air, shall be subjected to radiation (as with a cobalt bomb) at a rate of approximately 0.1 Mrad/h - 1 Mrad/h (1 kGy/h - 10 kGy/h) for a total dosage of 10 Mrad (100 kGy). A test for ultimate elongation shall be carried out after the exposure to nuclear radiation has been completed.

6.4 Tests on Complete Seals

6.4.1 Structural Integrity of Seal: Inflate the unrestrained seal to 345 kPa pressure, then isolate the air source and observe the seal for 1 h. If there is no evidence of leakage, immerse the inflated seal without undue distortion under a 25 mm head of water in a flat bed tank. Any evidence of leakage other than that due to permeation is cause for rejection.

6.4.2 Pressure Retention: Immediately following the test for structural strength in para 6.4.1 above, reduce the seal pressure to 275 kPa. Hold this pressure constant for 1 min. After this 1 min period, isolate the air source at the seal and observe the seal pressure for a 1 h period. If the pressure falls below 240 kPa during this period, then continue observation for an additional 1 h period. The seal is acceptable if the seal pressure has not dropped below 210 kPa at the end of the second 1 h period.

6.4.3 Collapse Time: Immediately following the test for pressure retention, (para 6.4.2), inflate the seal to a pressure of 275 kPa. Measure the time for complete collapse (see para 5.1.1) after relief of pressure.

6.4.4 Leakage Rate Across the Seal

6.4.4.1 With the seal mounted as described in para 6.4.5.1 and inflated to 210 kPa, one side of the seal shall be subjected to air at 120 kPa, in such a manner as to attempt to effect leakage past the striker-head face and the foot (see drawing) while the other side of the seal is being maintained at room temperature and atmospheric pressure. The leakage rate, over a one-week period, shall not be more than 350 mL/min per unit length in metres of the seal.

6.4.4.2 Repeat the above except that the seal shall be inflated to 240 kPa internal pressure for one hour. The maximum permissible leakage shall be 150 mL/min per unit length in metres of the seal.

6.4.5 Tests for Distortion and Striker Head Movement

6.4.5.1 A complete seal shall be mounted on a mockup of the corresponding airlock or containment and confinement area door with the service clearance between the seal retainer and the sealing surface. On inflation to the design pressure, the seal shall not fold, wrinkle or collapse, particularly at the door corners and wherever else the curvature is such that the above are likely to occur.

6.4.5.2 A short section of the test fixture used for the test described in para 6.4.5.1 shall be constructed of transparent plastic at the sealing surface and the seal mounted as for that test. The seal shall be gradually inflated and the movement of the striker head observed as the seal unfolds. The striker head shall be fully aligned with the sealing surface (door frame) at the time of contact. There shall be no evidence of warping, twisting or folding.

6.4.6 Fatique Resistance

6.4.6.1 A complete seal, used in the tests described in para 6.4.5 shall be subjected to complete inflation-deflation cycles at 23 + 20°C. There shall be a 10 min. waiting period between cycles. The inflation component of the cycle shall be achieved by the application of air at 240 kPa. The deflation component of the cycle shall be achieved by exhausting air from the seal to the atmosphere.

6.4.6.2 10 000 cycles shall be completed for qualification, and 1000 cycles shall be completed on randomly selected seals when testing batches of seals to be shipped.

6.4.6.3 On completion of the fatigue tests, no cracks or delaminations shall be apparent to the unaided eye. The seal shall then be subjected to the Structural Integrity (para 6.4.1), Pressure Retention, (para 6.4.2), Collapse Time (papa 6.4.3) and Leakage Rate (para 6.4.4) Tests. Results of these tests shall satisfy the requirements shown in Table 1.

6.4.7 Collapse Time: Sample seals after temperature aging shall be maintained at design pressure for seven days (7), one seal at minus 7°C, a second at plus 50°C. After relief of pressure at these temperatures, the time for complete collapse shall be measured.

TABLE 3.1-1: TABLE OF REQUIREMENTS

PROPERTY	REF PARA	UNIT	REQUIREMENT
1. Striker Head			
(a) width		mm	7.5 minimum
(b) serrations		grooves	4 minimum
2. Sealing Foot			Shall fit the retainer groove
3. Fabric Reinforcement			
(a) number of plies in wall		-	1 minimum
(b) number of plies in foot		-	2 minimum
(c) ply overlap		-	Located in seal foot
(d) splice location		-	Not at a corner
4. Elastomer Cover Layer Thickness		mm	One ply 0.2 minimum Two plies 0.1 minimum
5. Elastomer			
(a) type		-	Silicone (Phenyl type), red
(b) stability		-	pass
(c) tensile strength		kN/m^2	9.0 minimum
(d) ultimate elongation		percent	500 minimum
(e) tear strength		kN/m	30 minimum
(f) ultimate elongation after 10 Mrad radiation	6.3	percent	100 minimum
6. Structural Integrity of Seal	6.4.1	-	No leak type bubbles
7. Pressure Retention Time	6.4.2	hours	1.0 minimum
8. Collapse Time	6.4.3 6.4.7	seconds	10 maximum
9. Leakage Rate Across Seal	6.4.4	mL/min/m of seal	150 max @ 240 kPa 350 max @ 210 kPa
10. Distortion and Striker Head Movement	6.4.5	-	pass
11. Fatigue	6.4.6	cycles	pass

APPENDIX 3.2

AIRLOCK SEAL INSPECTION AND TESTING

Table 3.2-1: Pickering A, Record of Airlock Inspection and Testing

Airlock Inspection, Test 41

		Percent Completion of Scheduled Tests			
		U1	U2	U3	U4
1976	Three times/day	93	92	93	93
1977		92	95	93	93
1978		93	96	95	89
1979		98	98	98	97
1980		100	100	100	100
1981		100	100	100	100
1982		100	100	100	100
1983		100	100	100	100
1984		99.9	100	100	100
1985	Two times/day	100	100	100	100

Table 3.2-2: Pickering B, Airlock Inspection, Test 46

Routine testing of containment began in October 1982.

		Percent Completion			
		U5	U6	U7	U8
1983	once/shift	100	100		
1984	once/shift	100	100	100	
1985	once/shift	100	100	100	100

Table 3.2-3: Bruce A, Airlock Test Performance

1976-1980	no regular testing reported	
1981	only TC6	leak rate test done
1983	AL2	leak rate, 3 units (Test 4.1A)
	AL6, U2 & U3	leak rate (Test 4.30)
1984	AL2	leak rate (Test 4.1A)
	TC6	leak rate (Test 4.3)
	AL6, U1, U3 & U4	leak rate (Test 4.30)
	AL17 & AL18	leak rate (Test 4.31)
		seal leak rate (Test 4.32)
1985	scheduled airlock	tests completed

APPENDIX 3.3

AIRLOCK UNAVAILABILITY AND FAILURE RATE DATA

Table 3.3-1: Pickering A, Airlock Unavailability

	Unit 1	Unit 2	Unit 3	Unit 4	Expected
1971	"well below" $1x10^{-3}$				
1972	"well below" $1x10^{-3}$				
1973	$1.14x10^{-3}$	$3.43x10^{-3}$	$3.54x10^{-3}$	$.84x10^{-3}$	$1.8x10^{-4}$ per unit
1974	$1.09x10^{-3}$	$1.49x10^{-3}$	$1.1x10^{-3}$	$2x10^{-3}$	
1975	0	$2.3x10^{-4}$	$1.03x10^{-3}$	$1x10^{-3}$	
1976	$8.2x10^{-3}$	$8.2x10^{-3}$	$8.2x10^{-3}$	$8.2x10^{-3}$	
1977	$4.3x10^{-3}$	$5.0x10^{-5}$	$7.0x10^{-5}$	$3x10^{-5}$	
1978	0	$3.0x10^{-5}$	$2.0x10^{-5}$	0	
1979	0	0	0	0	
1980	0	0	0	0	
1981	0	0	0	0	
1982	0	0	0	0	
1983	0	0	0	0	
1984	0	0	0.003	0	
1985	0	0	0.01	0	
1986	0	0	0	0	

Table 3.3-2: Bruce A and Bruce B, Airlock Unavailability

Bruce A		Bruce B
1976	0	
1977	0.28 Airlock Seals	
1978	N/A	
1974	0.54	
1980	0	
1981	$0.7x10^{-3}$ year/year	
1982	0.02	
1983	0.02	
1984	0	N/A
1985	0.02	Airlock & Transfer Chamber 0

Table 3.3-3: Pt. Lepreau, Seal Failure Rates and Seal Unavailability

	Personnel Airlock	Equipment Dr. Main Airlock	Personnel Dr. Main Airlock
1982 Failures/ Component year	4.4	0.55	4.4
Unavail/year	3.4×10^{-1}	6.1×10^{-3}	2.2×10^{-1}
1983 Failures/ Component year	3.25	2.55	2.5
Unavail/year	4.33×10^{-2}	3.16×10^{-2}	3.69×10^{-2}
1984 Failures Component year	1.25	1.0	0.75
Unavail/year	3.83×10^{-2}	3.44×10^{-3}	8.44×10^{-4}
1985 Failures Component/year	3.4	1.0	0.5
Unavail/year	6.0×10^{-2}	1.1×10^{-1}	3.5×10^{-3}

Table 3.3-4: Airlock Seals, Failure Rate Data

	Component In-Service Yrs	No. of Failures	Faults/ Component Yr	Period
Pickering A	1342.5	300 ...	0.22 0.708	1982 End 1985
Bruce A	470	107	0.23	End 1985
Bruce B	135.2	50	1.48	End 1985
Pt. Lepreau	41.1	61	1.48	End 1985

APPENDIX 4

FUELLING MACHINE HOSES

Note: Appendix Numbering Refers to Subsection Numbers in Chapter C

4.1 Fuelling Machine Hoses - Extracts from Quarterly Technical Reports

APPENDIX 4.1

FUELLING MACHINE HOSES - EXTRACTS FROM QUARTERLY TECHNICAL REPORTS

Bruce A

1978: 4 head hose, 1 catenary hose failure
1980: A total of 52 hose failures occurred, as reported in the QTRs. Four experimental hoses with stainless steel braid were installed on each of two heads
1981: 13 head hoses, 14 catenary hose failures
1982: 11 head hoses, 5 catenary hose failures
1983: 9 head hoses, 1 catenary hose failure
1984: Completed changeover to EPR/Neoprene hoses

One head hose failure occurred in the 3rd Qtr, 1984, of a CR166-16, EPR liner, CS braid hose, installed April 1984. The liner was in excellent shape, but the CS braiding under the fitting was badly corroded, due to incorrect nipple dimensions. This was thought to be caused by numerous re-uses of fittings. New fittings were used until a go/no-go test for fittings was developed.

In 1985, routine catenary inspection on the SW quadrant revealed hoses, B, C, F and G were worn through the rubber covering, exposing the carbon steel braiding. The covering on hose B appeared to have separated from the first layer of braiding (32" from the fuelling machine head), exposing the entire braid for a length of about 1'. Hoses B, C, F and G were replaced, and refuelling continued. The hoses were suspected of being oversized by about 6", which would have allowed the hose to bulge outside the clamping bars and rub against the catenary well. A 2" section was sent to Ontario Hydro Research for analysis.

In the 4th Qtr, 1985, six catenary hoses were removed from service. All hoses with cracked and peeling outer jackets were removed from service. In-service lives were 18 to 33 months, compared to the expected 60 months. In all cases, hose liners appeared to be in good condition. Hose sections were sent to Ontario Hydro Research for analysis and recommendation on improved jacket material.

In the 1st Qtr, 1986, six more head/catenary hoses were removed from service, with cracked and peeling outer jackets. In-service lives were 21 to 26 months. In an effort to extend operating life, prototype hoses were being developed by Aeroquip and Ontario Hydro Research. The outer jacket of the new hose was to be changed from Neoprene to a mixture of EP/nitrile. These hoses are expected to have a five-year life.

In the 3rd Qtr, 1986, a fuelling machine head hose could not be pressurized. Upon investigation, D_2O was seen spraying from south east catenary hose H (in-service only ten days). The hose was removed and sectioned at the point of failure (24' from end). Inspection of the hose liner revealed 3-1/8" diameter holes. Liner material from these holes had been extruded through the steel braiding, which was still intact. The liner area surrounding the holes had numerous dimples (thin areas) as though bubbles or inclusions were present during the manufacturing process (hose manufacturing date, October 1986).

In the 4th Qtr, 19 elastomers hoses were removed from the D_2O auxiliary system with in-service lives ranging from 23 to 44 months. Although all hoses had cracked and peeling outer jackets, the liners remained soft and flexible.

Another hose failure occurred 86-11-01 on the south extension catenary hose 'A'. Again, a 1/8" diameter hole was found at the point of rupture. (Manufacturing date, October 1987, in-service life 17 channels). The manufacturer was informed and photographs sent for analysis.

APPENDIX 5

CABLE PENETRATIONS

Note: Appendix Numbering Refers to Subsection Numbers in Chapter C

5.1 Records of Penetration Leak Testing

5.2 Cable Penetrations - Extracts from Quarterly Technical Reports

APPENDIX 5.1

RECORDS OF PENETRATION LEAK TESTING

Table 5.1-1: Pickering A: Reactor Building On-Power Pressure Test (Test C-12 PF-647, Test 47)

Required Frequency: Quarterly

	Percent Completion				
	U1	U2	U3	U4	
1978	75	75	75	75	R/B on power pressure test initially performed in June 1978
1979	100	100	100	100	
1980	100	100	100	100	
1981	100	100	100	100	
1982	75	75	75	75	2nd Qtr test not completed, due to extended outage of Unit 1
1983	100	100	100	100	
1984	75	75	75	75	containment bulk-head isolation pressure testing
1985	N/A	N/A	100	100	Unit 1 & Unit 2 did not require testing, as a result of con-tainment bulkhead isolation pressure testing

Table 5.1-2 Pickering B: Reactor Building On-Power Pressure Test (Test C-13)

Required frequency: Quarterly.

	Percent Completion			
	U5	U6	U7	U8
1983	100	100	not	applicable
1984	100	100	100	
1985	100	100	100	

Table 5.1-3 Bruce A: Electrical Penetrations Leak Test
(Test 4.18)

Required Frequency: Five year cycle

	Percent Completion	
1978	80	Unit 3 penetrations tested
1979	0	no tests this year
1980	0	no tests this year
1981	51	units 0 and 2 tested
1982)	no results	
1983)	reported	
1984)		
1985	100	20% of all electrical penetrations tested

APPENDIX 5.2

CABLE PENETRATIONS - EXTRACTS FROM QUARTERLY TECHNICAL REPORTS

Pickering A

1st Qtr, 1975: Unit 3 performed its first reactor building pressure test, and found 30 minor leaks, 17 of these were around the dome plug where the weatherproof seal had deteriorated, and 13 were at various penetrations. The dome plug seal was repaired with Silicone Rubber, but no repairs were done to the penetrations because of their small size.

2nd Qtr, 1975: Unit 4 reactor building leak test was performed, and 11 small leaks were found at pipe and cable penetrations. All were sealed with a rubber sealing compound.

3rd Qtr, 1975: Unit 2 reactor building leak test was performed. Minor leaks were found, and these were sealed.

4th Qtr, 1975: Unit 1 reactor building leak test was performed. Minor leaks were found and sealed.

1976: No significant events.

1st Qtr, 1977: Unit 2 leak check of all penetrations (275) with the reactor building pressurized to 1 psig. The containment leak tightness spec was met.

2nd Qtr, 1977: Leaks were found through the cable penetrations from the boiler room of Unit 3. Penetrations were resealed.

4th Qtr, 1977 U1 leak at a cable penetration, resealed.

No further reported leaks in Qtrs.

Bruce A

2nd Qtr, 1978: Several electrical penetrations failed leak rate test 4.18. Since the leaks were not considered serious, repair was done during the following outage.

2nd Qtr, 1981: Two penetrations failed test 4.18. No leakage was found on the service side (i.e. primary plate assembly). A sealing compound was applied to the containment side, and the leaks stopped.

APPENDIX A

STANDARDS OF THE AMERICAN SOCIETY OF TESTING AND MATERIALS (ASTM), APPLICABLE TO ELASTOMERS

D15 Sample preparation for Physical Testing of Rubber Products

D378 Methods of Testing Flat Rubber Belting

D380 Testing Rubber Hose

D412 Test methods for rubber properties in Tension

D413 Rubber property-Adhesion to flexible substrate

D471 Test method for rubber property-Effect of liquids

D573 Rubber-Deterioration in an air oven

D624 Tear Resistance of Volcanized Rubber

D832 Rubber conditioning for low temperature testing

D1053 Measuring rubber property-Stiffening at low temperature using a torsional wire apparatus

D1149 Test method for rubber deterioration-Surface Ozone Cracking in a chamber (flat specimen)

D1390 Test method for rubber property-Stress relaxation in Compression

D1672 Exposure of Polymeric materials to high energy radiation

D1708 Tensile Properties of Plastics by Use of Microtensile Specimens

D2240 Test method for Rubber Property-Durometer Hardness

D3182 Practice for Rubber-Materials, Equipment, and Procedures for mixing standard components and Preparing standard vulcanized sheets

D3183 Rubber-Preparation of Pieces for Test from Other than Standards Vulcanized Sheets

D3677 Rubber-Identification by Infrared Spectrophotometry

F145 Flat Faced Gasketed Joint Assemblies, Recommended Practice for Evaluating

Testing of Elastomers

A variety of test procedures for testing of elastomers are described in ASTM volumes 09.01 and 09.02. The most widely used test procedures are summarized here:

D395 Compression Set: The dimensional change of a specimen subjected to constant compression stress or strain is measured. Specimens may be subjected to heating or radiation. This is an important test for gaskets and seals.

D412 Tensile Properties: Tensile properties such as tensile strength, ultimate elongation and tensile stress at given elongation are measured.

D471 Effect of Liquids: Specimens are immersed in liquids and change of mass, or volume, or tensile strength, elongation and hardness are measured. The liquid may be a service liquid or one of the ASTM standard oils or fuels.

D573 Determination in an Air Oven: Tensile properties of rubber specimens before and after oven aging are evaluated.

D624 Tear Resistance: Resistance of rubber to tearing is measured. For extruded goods, tear resistance in the machined direction is different from that in cross-direction.

D865 Deterioration by Heating in Air: This is similar to D573, but the specimens are individually enclosed in test tubes.

D1149 Ozone Resistance: The sample is stretched and exposed to ozone. The time required for cracking to occur is measured.

D1390 Stress Relaxation: The reduction of stress exerted by a rubber specimen, subject to a constant compressive strain is measured as a function of time. Specimens may be subjected to heat or radiation. This is an important test for gaskets and seals.

D2240 Hardness: Elastomer hardness is measured by pushing a spring loaded pin into the surface. Soft and medium rubbers are designated by 'Shore A' scale readings from 20 (softest) to 100. The "Shore D' is graduated so that the needle point reads 100 on a smooth glass surface. A hardness reading of 100 Shore A is approximately equal to a Shore D reading of 50.

APPENDIX B

EXTRACTS FROM CSA STANDARD CAN3-N287.2-M82

Material Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants

7.5.1 General

7.5.1.1 All materials shall be qualified by the tests required in Clause 7.5.2 for liner materials and in Clause 7.5.3 for joint sealant materials.

7.5.1.2 The tests shall be performed in a laboratory approved by the regulatory authority.

7.5.2 Liner Material

7.5.2.1 Radiation Resistance. The effect of gamma radiation in air on the physical properties of each constituent material and on the complete liner system shall be determined as follows:

(a) The test shall be performed on a sample specimen of the liner material applied to a concrete substrate whose minimum dimensions are 75 mm x 50 mm x 6 mm thick;

(b) Exposure to radiation shall be in a gammacell at a temperature of 32°C and at a dose rate of 1.8×10^6 rad/h;

(c) The minimum test dosage of radiation shall be equal to the specified maximum accumulated in-service dosage predicted for the life of the plant;

(d) For the purpose of providing reference information, the test shall be continued to failure; and

(e) The material shall be deemed to have failed at the first evidence of blistering, cracking, or loss of adhesion, either between coats or between the liner and the substrate.

7.5.2.4 Decontamination. Test samples of the liner material, applied to a concrete substrate shall:

(a) Exhibit no cracking, blistering, softening, or loss of adhesion: nor more than slight surface etching, when tested in accordance with CGSB Standard 1-GP-71, Methods of Testing Paints and Pigments, as follows:

(i) Method 105.2 exposure to a 5% solution of sulphuric acid for 24 h; and

(ii) Method 106.1, exposure to a 5% solution of sodium hydroxide for 24 h; and

(b) Have a decontamination factor equal to that required by the performance specification, when calculated in accordance with the requirements of BSI Standard 4247: Part 1, Method of Test for Ease of Decontamination.

7.5.3 Joint Sealant Materials

7.5.3.1 Radiation Resistance. The sealant material shall exhibit no evidence of blistering, cracking, or other signs of deterioration when tested in accordance with Clause 7.5.2.1.

7.5.3.2 Decontamination. The sealant material shall have a decontamination factor equal to that required by the performance specification when tested in accordance with Clause 7.5.2.4.

7.5.3.3 Elasticity. The sealant material, when exposed to the specified maximum accumulated in-service radiation dose, in accordance with Clause 7.5.2.1(c), shall attain an ultimate elongation of not less than 100%, when compared to a sample not exposed to radiation, and when each sample is tested in accordance with ANSI/ASTM Standard D412, Rubber Properties in Tension.

7.5.3.4 Hardness. A sealant material, cured a maximum of 7 d and tested in accordance with ANSI/ASTM Standard D2240, Rubber Property - Durometer Hardness, shall have:

(a) A minimum Shore "A" durometer hardness of 30 for floor joint sealants; and

(b) A shore "A" durometer hardness between 15 and 25 for wall joint sealants.

The Shore "A" durometer hardness required in Items (a) and (b) shall not vary more than +5 units of hardness after the sealant material is exposed to the specified maximum accumulated in-service radiation dose in accordance with Clause 7.5.2.1(c).

10. Organic Materials

10.1 General

10.1.1 The required given herein shall be capable for the following:

(a) Rubber products used as flexible joints that join class containment components:

(b) Polyvinyl chloride products used as waterstops in concrete joints; and

(c) Materials such as polyethylene, neoprene, or butyl rubber, used as concrete joint filler or concrete joint backup material.

10.1.2 Rubber products used as flexible joints shall satisfy the performance requirements and service conditions specified for the particular application and, as a minimum, shall be qualified by the tests required in Clause 10.2.

10.1.3 Materials used as waterstops and materials used as concrete joint filler or joint backup shall satisfy the performance requirements and service conditions specified for the particular application.

10.2 Tests

10.2.1 Properties Before Aging. The materials shall be qualified by tests on representative samples in accordance with Table 1.

10.2.2 Properties After Aging. After the materials have been heat aged for 28 d at a temperature of 70°C, they shall be qualified by tests on representative samples in accordance with Table 2.

10.2.3 Performance Tests. The manufactured products shall be qualified by tests on representative samples in accordance with Table 3.

10.2.4 Radiation Resistance. The effect of gamma radiation in air on the physical properties of the material shall be determined as follows:

(a) The test shall be performed on a sample specimen of the material whose minimum dimensions are 75 mm x 50 mm;

(b) Exposure to radiation shall be in a gammacell at a temperature of 32°C and at a dose rate of 1.8×10^6 Rad/h;

(c) The minimum test dosage of radiation shall be equal to the specified maximum accumulated in-service dosage predicated for the life of the plant;

(d) For the purpose of providing reference information, the test shall be continued to failure; and

(e) The material shall be unacceptable if there is any evidence of blistering, cracking, or loss of adhesion.

Table 1: Properties Before Aging

Property	Test Method	Acceptance
Tensile strength	ASTM D378(Die C)	10 MPa Min.
Ultimate elongation	ASTM D378(Die C)	300% Min.
Tear resistance	ASTM D624(Die B)	35kN/m Min.
Water resistance	Immersed in distilled water for 7 d at 70°C	
(a) Absorption	ASTM D668	0.03% Max. by Mass
(b) Hardness	ASTM D2240	Maximum change ±5 Units
(c) Tackiness		No indication by touch

Table 2: Properties After Heat Aging

Property	Test Method	Acceptance
Tensile strength	ASTM D378(Die c)	90% of unaged sample
Ultimate elongation	ASTM D378(Die C)	85% of unaged sample
Tear resistance	ASTM D624(Die B)	90% of unaged sample
Ozone resistance	ASTM D1149 Partial pressure of ozone 1.01 MPa	No visible cracking at 500 h
Stress relaxation	ASTM D1390	
(a) During aging	-	50% Max.
(b) Low temperature	7 d at -29°C	
(i) Initial	-	50% Max.
(ii) After 7 d	-	75% Max.

Table 3: Properties After Heat Aging

Property	Test Method	Acceptance
Splice strength	ASTM D378	60% of unshaped sample
Adhesion Rubber/Fabric	ASTM D413	2 kN/m Min.
Fabric tensile strength	-	140 kN/m Min.
Radiation resistance	Refer to Clause 10.24	No cracking blistering or loss of adhesion

EXTRACTS FROM CSA STANDARD CAN3-N287.7-M80

In-service Examination and Testing Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants

5.2 Frequency of Examinations and/or Tests

5.2.1 Concrete Components and Metallic Parts
Subsequent to the in-service date of the containment system all concrete components and metallic parts shall be examined and/or tested a minimum of once every 5 years.

Note: For multi-unit stations 20% per year of the total plant "Class" containment may be included with annual plant maintenance where such a containment inspection program has been approved by the Authority.

5.2.2 Non-metallic Liners and Organic Parts
Subsequent to the in-service date of the containment system all non-metallic liners and organic parts designated as class containment shall be examined and/or tested a minimum of once every 2 years and once every year, respectively.

5.2.3 After an Abnormal/Environmental Occurrence
Immediately following the occurrence of any abnormal/environmental loads, which are specified in the design specification, all class containment components shall be subjected to a visual examination and such non-destructive examinations as required to evaluate the integrity of the structure.

5.2.4 After Deterioration
The frequencies of examination and testing required by Clauses 5.2.1 and 5.2.2 shall be increased for components or parts which have exhibited significant deterioration and which may warrant future repair or replacement.